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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

**INTEGRATION OF ROBOTICS AND
3D VISUALIZATION TO MODERNIZE THE
EXPEDITIONARY WARFARE DEMONSTRATOR (EWD)**

by

Christian R. Fitzpatrick

September 2009

Thesis Co-Advisors:

Don Brutzman
Amela Sadagic

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**INTEGRATION OF ROBOTICS AND 3D VISUALIZATION TO MODERNIZE
THE EXPEDITIONARY WARFARE DEMONSTRATOR (EWD)**

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Major, United States Marine Corps
B.S., United States Air Force Academy, 1995

Submitted in partial fulfillment of the
requirements for the degree of

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MODELING, VIRTUAL ENVIRONMENTS, AND SIMULATION (MOVES)**

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ABSTRACT

In the summer of 2008, the Commandant of the Marine Corps (CMC) released a message to all Marines and Sailors detailing plans to revitalize U.S. naval amphibious competency. Current responsibilities in Iraq and Afghanistan have significantly reduced available training time causing overall amphibious readiness to suffer. In response, this thesis evaluates 3D visualization techniques and other virtual environment technologies available to support these mission-critical training goals. The focus of this research is to modernize the Expeditionary Warfare Demonstrator (EWD) located aboard Naval Amphibious Base (NAB) Little Creek, Virginia. The EWD has been used to demonstrate doctrine, tactics, and procedures for all phases of amphibious operations to large groups of Navy, Marine Corps, Joint, Coalition, and civilian personnel for the last 55 years. However, it no longer reflects current doctrine and is therefore losing credibility and effectiveness.

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LIST OF ACRONYMS AND ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
AAR	After Action Review
ACAT	Acquisition Category
AFRL	Air Force Research Laboratory
AMEX	Army Model Exchange (https://modelexchange.army.mil)
ARG	Amphibious Ready Group
ARL	Army Research Laboratory
ASCII	American Standard Code for Information Interchange
BASE-IT	Behavior Analysis and Synthesis for Intelligent Training
BRL-CAD	Ballistics Research Laboratory Computer-aided-design software
C14N	Canonicalization
C4I2	Command, Control, Communications, Computers, Intelligence, and Interoperability
CAS	Close Air Support
CAT	Crisis Action Team
CE	Command Element
CMC	Commandant of the Marine Corps
COA	Course of Action
COTS	Commercial Off-the-shelf
CSG	Carrier Strike Group

DOTMLPF	Doctrine, Organization, Training, Material, Leadership, Personnel, Facilities
DVTE	Deployable Virtual Training Environment
EFEX	Expeditionary Fires Exercise
ESG	Expeditionary Strike Group
EWD	Expeditionary Warfare Demonstrator
EWTGLANT	Expeditionary Warfare Training Group Atlantic
FAA	Functional Area Analysis
FAC	Forward Air Controller
FARP	Forward Arming and Refueling Point
FNA	Functional Needs Analysis
FOUO	For Official Use Only
FTP	File Transfer Protocol
GOPLATS	Gas and Oil Platforms
GSoC	Google Summer of Code
HA/DR	Humanitarian Assistance/Disaster Relief
HTTP	Hypertext Transfer Protocol
IED	Improvised Explosive Device
IEEE	Institute for Electrical and Electronic Engineers
ISM	Industrial, Scientific, and Medical
ISR	Intelligence, Surveillance and Reconnaissance
ISO	International Organization for Standardization
ITS	Individual Training Standards
JCIDS	Joint Capabilities Integration Development System

JGW	Joint Photographer's Expert Group World file
JPEG	Joint Photographer's Expert Group
JSAF	Joint Semi-autonomous Force
JTAC	Joint Terminal Air Controller
LED	Light-emitting Diode
LIDAR	Light Detection and Ranging
LOD	Level of Detail
MAGTF	Marine Air Ground Task Force
METL	Mission Essential Task List
MEU	Marine Expeditionary Unit
MOUT	Military Operations in Urban Terrain
NAWC-TSD	Naval Air Warfare Center Training Systems Division
NEO	Non-combatant Evacuation Operation
NGIA	National Geospatial Intelligence Agency
NITF	National Imagery Transmission Format
ONR	Office of Naval Research
OMFTS	Operational Maneuver from the Sea
PEO STRI	Program Executive Office for Simulation, Training and Instrumentation
PHIBRON	Amphibious Squadron
PMTRASYS	Program Manager for Training Systems
PTP	Predeployment Training Program
R2P2	Rapid Response Planning Process
RDECOM	Research, Development and Engineering Command

SA	Situational Awareness
SAVAGE	Scenario Authoring and Visualization for Advanced Graphical Simulations
SIGGRAPH	Special Interest Group Graphics
SMAL	SAVAGE Modeling and Analysis Language
SunSPOT	Sun's Small Programmable Object Technology
SurfTacs	Surface Tactics
SWAT	Special Weapons and Tactics
TBS	The Basic School, MCB Quantico, VA
TECOM	Marine Corps Training and Education Command
TLAM	Tomahawk Land Attack Missile
TLCTS	Tactical Language Cultural Training System
TRAP	Tactical Recovery of Aircraft and Personnel
TTP	Tactics, Techniques and Procedures
UAV	Unmanned Aerial Vehicle
UNIL	Unclassified National Information Library
VBSS	Vessel Board Search and Seizure
WARP	Web Access and Retrieval Portal
X3D	Extensible 3D Graphics
XML	Extensible Markup Language

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Thanks to Ray Lowman and Stephanie Brown from the Army Model Exchange. They tracked my progress continually and even visited NPS during my last quarter to lend assistance. Thanks to Michael Klug, Mark Holzbach, Thomas Burnett, and Rafael Fajardo from Zebra Imaging, Inc. After meeting at SIGGRAPH 2008, they continually provided explanation and guidance on the tactical use of 3D holograms to help me complete this work. Thank you to Dennis Lenahan for his continual support. Dennis spent many hours compiling historical data on the facility and his inputs are seen throughout this thesis. Dennis is truly committed to the EWD and the training it provides to Sailors and Marines. Thanks to LtCol Walt Yates for his guidance. Even while deployed to Iraq, he continued to check my progress and added input to the acquisition portion of this work. Finally, I would like to thank Mike Bailey, Terry Norbraten, and Jeff Weekley for always taking time to answer questions and offer assistance. Their help and guidance is definitely helped me complete this project. Thank you.

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I. INTRODUCTION

A. OVERVIEW

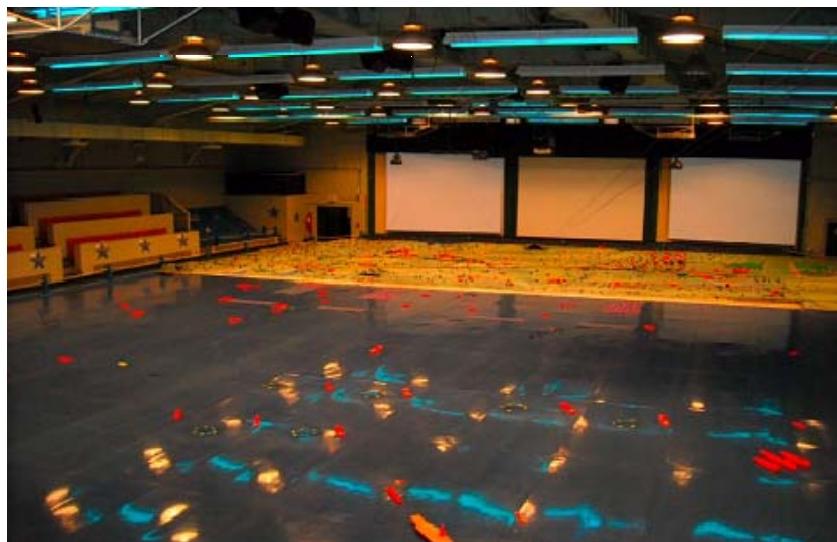
The goal of this work is to provide technology recommendations to Marine Corps Training and Education Command (TECOM), Naval Air Warfare Center-Training Systems Division (NAWC-TSD), and Marine Corps Systems Command-Program Manager Training Systems (MCSC, PMTRASYS) for the modernization of the Expeditionary Warfare Demonstrator (EWD) located aboard NAB Little Creek, Virginia. The recommendations focus on two areas: wireless communication for robotic ship models using Sun's Small Programmable Object Technology (SunSPOT) and visualization of enhanced digital terrain using the geospatial component of Extensible 3D Graphics (X3D). Throughout this work, examples of both are presented showing how the technologies can be applied training at the EWD. The target training audience for this work is the Marine Expeditionary Unit (MEU) and their execution of the Rapid Response Planning Process (R2P2) during predeployment training.

B. MOTIVATION

In the summer of 2008, the Commandant of the Marine Corps (CMC) released a message to all Marines and Sailors commanding them to reestablish their traditional roles as “fighters from the sea” (Conway, 2008, July 30). As the Global War on Terrorism (GWOT) completed its fifth year that summer, the Marine Corps was landlocked and seemed to be slowly moving away from its naval heritage. Although the nation’s global responsibilities always require a strong Navy and Marine Corps presence abroad, these responsibilities also require proficiency as an amphibious fighting force. The Commandant wants this proficiency to be the primary focus for Sailors and Marines. Current training and readiness, then, have to compensate for the lack of amphibious focus due to actual missions abroad. No matter how difficult the challenges faced, the nation still depends on the Marine Corps when an amphibious capability is required, and the expectations for success will be high.

To meet the call, the Marine Corps and Navy must review how they prepare for expeditionary operations from the sea. Current amphibious units, including the Marine Expeditionary Unit (MEU), go through an extensive 3-month, predeployment training cycle prior to a 6-month deployment aboard an amphibious ship. During their initial three months, they complete training in the Rapid Response Planning Process (R2P2) to guide their mission planning. The MEU's competence is typically measured in its ability to quickly plan within the R2P2 framework. Considering its importance, this work focuses on this process and, through research, contributes new capabilities to support the Commandant's plan. More specifically, this study reviews how enhanced 3D visualization impacts R2P2 and how it could be better incorporated into the process.

Numerous 3D visualization tools are now available but have yet to reach the amphibious training arena. Nowhere is this more apparent than at the outdated EWD shown in Figure 1. This facility, once considered the premier amphibious training demonstrator in the world, is now a hallmark for the fading concern with striking enemies from the sea. The combination of the CMC's guidance and the EWD's untapped potential to accurately model an amphibious assault comprise a prime opportunity to restore the relevance of the EWD and update its capabilities to become a more effective maritime training tool.



**Figure 1. Expeditionary Warfare Demonstrator (EWD) Demonstration Area
(measuring 96 feet by 69 feet)**

C. CRITERIA FOR RECOMMENDING UPDATED SOLUTIONS

The most successful training devices in the U.S. military today share a unique set of criteria often difficult to achieve, but critical to its lifecycle. Successful training tool implementation depends heavily on strict adherence to these criteria during development. In making appropriate recommendations to enhance visualization for the EWD, a specific set of guidelines were established early in the process to ensure this work was aimed toward the solutions characterized as flexible, easy to maintain and robust.

First and foremost, the recommended software solutions should, whenever possible, be *open source* efforts to encourage collaboration and continued development among Marines and Sailors using the EWD. This approach enables an easier path towards future upgrades and extensions of the system, benefiting from the “wisdom of the crowd” and being free from costly license issues. For the EWD to be a flexible trainer, the software tools used to create the realistic training visualizations must be intuitive and supported by a large user community ready to offer support. The alternative—proprietary software—is normally developed for a specific training application and the cost for ongoing support is regularly added to the cost of the actual software itself. In contrast, mature, open source software (OSS) is normally completely free and often develops continues to develop over time based on extensive collaboration among users (Shearer, 2008). Using OSS also avoids increased costs caused by vendor lock-in. This occurs when a user forced into using a specific software or hardware tool for training, because switching to a different proprietary solution becomes more expensive than paying the vendor for an upgrade or new system (Shearer, 2008). Recognizing these benefits, the Chief Information Officer of the Navy gave OSS the same status as commercial and government off-the-shelf software products in 2007 (Sanders, 2007). This is a significant step and that guidance was clearly used for this work.

Second, the recommended solutions must comply with *open standards*. This is partially implied by the first criterion, but additional points must be made. The 2009 Marine Corps Modeling and Simulation (M&S) *Master Plan* recommends increased interoperability, commonality and re-use of modeling and simulation tools, data and services across the USMC (Akst, 2009). Although this goal seems achievable, relatively

little re-use of M&S tools occurs across the services. The EWD may be a forum to display open source tools and show their ease of use while educating young Marines and Sailors. One additional note regarding the need for open standards with a project such as EWD modernization is the strict usage of metadata standards. These standards may allow Marines to easily find open source models for training online; therefore, training visualizations can be available whenever desired.

Finally, the *ease of use* is critical for the EWD, especially if it is planned for integration with the R2P2 planning framework. To create animated scenarios, a user needs a range of tools with a capability to easily “drop in” models within scenes relevant to an amphibious training scenario. An intuitive user interface allowing Marines and Sailors to produce relevant visualizations quickly and then have a staff view them on a large scale at the EWD would be a significant training advancement. Ease of use makes the training more robust and allows units to be more creative in their scenario development.

D. PROBLEM OVERVIEW

The EWD, originally constructed back in 1953, was the U.S. Military’s first joint maritime training simulator. It was and still is used to demonstrate doctrine, tactics, and procedures for all phases of amphibious operations to Navy, Marine Corps, Joint, Coalition and civilian leaders. Hosting over 3,600 personnel in 2007 and slightly more in 2008, the EWD attracts many different units, ranging from Naval Academy Midshipmen to Marine Corps Second Lieutenants from The Basic School (TBS). Unfortunately, current operational units tend not to use EWD.

The reason for this disconnect from operational tasking can be found by looking closely at the EWD itself. Currently, the aging demonstrator uses outdated technologies and equipment to recreate the ship-to-shore movements associated with an amphibious landing. With a combination of videos, movable models, and various audio-visual effects, the amphibious demonstration is quite impressive, but the Expeditionary Warfare Training Group Atlantic (EWTGLANT) Operations staff has determined that the EWD in its current configuration does not adequately reflect existing USMC doctrine.

In addition, even though its video and scripts were updated in 1993, the system still does not reflect current ship types and composition, nor does it adequately reflect the employment of a Marine Air Group Task Force (MAGTF) or Marine Expeditionary Brigade (MEB). These are all critical components of a Sailor's understanding of amphibious operations. In other words, the EWD falls short for both the Marine Corps and the Navy.

In response, TECOM, NAWC-TSD, and PMTRASYS are completing a Training Requirements Analysis of the EWD. As a part of their analysis, they have tasked the members of the SAVAGE Lab within the Modeling, Virtual Environments and Simulation (MOVES) Institute at the Naval Postgraduate School (NPS) to investigate and report on simulation technologies available to upgrade and modernize the facility. With numerous technologies available, the challenge of this work is to focus on those technologies that provide the most effective training.

The two issues greatly limiting the EWD in its current configuration are the ship models and the fixed-terrain display. First, the EWD uses mobile ship models controlled by the EWTGLANT staff via an archaic pulley system that precludes any changes in model movement. This work first investigates the use of wireless communication technology to move those models using Sun Microsystems' Small Programmable Object Technology (SunSPOT). SunSPOTs can be applied to execute coordinated movements of multiple ship models. The most interesting aspect of this technology is the plan to make the display interactive by allowing actual ship crews to make control inputs through a user interface—thus moving their specific ships. Adding realism, the new ship models will also maneuver on top of a projected display of a littoral region. Extensible 3D Graphics' (X3D) Geospatial Component can be used produce an X3D Earth model (Yoo & Brutzman, 2009). An example is shown in Figure 2. In a realistic display similar to this, each ship crew will be tasked to move its ship in order to support missions ashore within a training scenario. Notably, X3D Earth scenes can be created for any location across the globe.



Figure 2. X3D Earth Model of the San Diego Harbor

Second, the fixed terrain display shown in Figure 3 limits training to one scenario. This work investigates adding the flexibility of X3D Earth to expand the EWD's geographic coverage to the entire globe. Units can then train and plan missions using geospatial visualizations of any enemy objective area ashore. This can potentially enhance readiness in executing tactical maneuvers (Feibusch, Gagvani, & Williams, 1999). In addition, this work also investigates augmenting X3D scenes with animated models. By animating enemy activity within a scene, Marines can observe the speed and movement of ground forces near an objective area. Ultimately, these animated scenes will be developed to specifically help amphibious staffs coordinate and plan within the R2P2 framework previously introduced.



Figure 3. Fixed Terrain Display at the EWD

This work also investigates open source 3D models available for use within the EWD. The Army Model Exchange (AMEX) has a large repository of high-fidelity models, which may be useful in creating a repository of usable models for the EWD. The AMEX models will be tested for interoperability with X3D Earth and overall fidelity within X3D scenes.

Finally, this work investigates the usage of digital holography for the visualization and planning for actions at the objective. Digital holography is currently in use in Iraq and Afghanistan and may have training applications within the EWD. With this tool, individual Marines and small teams can potentially plan and rehearse missions into complex urban environments. Since the EWD is primarily a large staff-training tool, investigation of holography seeks to find a technology that may allow planning and training on the fire team level at the EWD. Overall, this work seeks to dramatically improve the EWD's flexibility and possibly assist the CMC with his vision of improving current and future amphibious readiness.

E. CMC GUIDANCE

In his message, the Commandant offers guidance along three paths to improve amphibious readiness. In addition, he sets specific dates at the end of 2008 and in 2009 to measure progress. This work was completed in September 2009 and forwarded to a Marine Corps Systems Command for possible future integration.

1. Execution

Since this research is linked closely with General Conway's directive, his message must be reviewed. His words are very specific:

We must institute a naval mindset by embracing our maritime traditions through mastery of our amphibious capabilities and core competencies. The revitalization of our amphibious competency will be accomplished by action along three pathways:

- (1) Policy, Doctrine, and Resources
- (2) Education
- (3) Operations and Training

Our initial aiming point for regaining our amphibious forcible entry capabilities is training to Brigade/Expeditionary Strike Group (ESG) Command Element (CE) Amphibious Assault Requirements. (Conway, 2008, July 30)

3D visualization has definite applications along each of the paths listed. Regarding policy and doctrine, animations of multiple scenarios can help an amphibious staff visualize numerous tactics, techniques and procedures (TTPs) necessary to developing new amphibious doctrine. Those same animations could also be used to educate Marines and Sailors on the complex coordination and execution required to successfully strike from the sea. In addition, use of these technologies within the MEU predeployment training cycles can support a consistent level of readiness.

2. Timeline and Directives

To start the process, the CMC set a target date of August 13, 2008 for an initial workshop to begin conceptual planning for the proposed MEB/ESG Command Element (CE) Amphibious Exercise planned for the second quarter of 2009. EWTGLANT at NAB Little Creek, VA, hosted the workshop to create a timeline leading towards the large-scale exercise. In addition, the CMC called for the creation of a MEB-level Planning Staff consisting of 40 personnel with enough diversity and expertise to coordinate such an intricate exercise. Although the challenges of creating a new staff while still supporting current operations is great, the CMC still did not want to stall progress in this effort. Reestablishing amphibious readiness was high priority.

Since the Expeditionary Warfare Training Group Atlantic (EWTGLANT) schedules and maintains the EWD, it is the primary customer for this research. The goal is to quickly complete this work and integrate recommendations into the target dates set at the initial workshop. The vision is for the EWD to become the backbone of the CMC's future training efforts.

F. CURRENT STATE OF THE EWD

In order to assess the starting point for this work, the researcher conducted a site visit to the EWD in August 2008. During the visit, the EWTGLANT staff played an

automated one-hour amphibious landing scenario on the massive 96-ft-by-69-ft demonstration table (shown in Figure 4). There are similar demonstrations that differ in length (1 hour, 30 minutes, and 15 minutes). The 1-hour version seen is typically used for units conducting initial familiarization training. It is augmented by video presentations, which go into detail on the planning considerations and interagency coordination required. During the demonstration, the overall movement of naval vessels was structured, methodical, and easily viewed from any seat within the EWD. Although the model scale was exaggerated for visibility, the proportional distances and speeds are realistic. Small boats accurately depicted the boat waves holding Marines inbound to the beach. Aircraft carriers were accurately depicted far from the beach with some aircraft flying around the models, which are attached by metal wire. Finally, some activities displayed on land included the destruction of a bridge, the movement of a surveillance helicopter along the beach, the delivery of bombs by an F/A-18 Hornet, and the air insertion of paratroopers from a KC-130 Hercules. The primary shortcoming of the demonstration is that the maneuvers cannot be updated to match current tactics. The data collected from the site survey was impressive, yet it was obvious that modernization was needed.



Figure 4. EWD Observers Watching the Beginning of an Hour-long Scenario as Ship Models Move into Place

G. EWD EXPANSION TO AMPHIBIOUS READINESS TRAINING

The Expeditionary Strike Group (ESG) was created shortly after the September 11 attacks. Although it appeared to be a new unit, most Marines and Sailors still recognize it as the combination of a Marine Expeditionary Unit (MEU) and Amphibious Ready Group (ARG). The one significant change is that a flag officer is now in command. In addition, some increased firepower was added—including Tomahawk Land Attack Missiles (TLAM) and a subsurface attack capability. With these slight variations, there was no need to radically change the year 2000 planning process used for MEU/ARG missions. To avoid confusion, all missions evaluated for the EWD modernization are referred to here as MEU missions. This work focuses on such missions as it attempts to enhance visualization along the three paths the Commandant outlines in his message. In order to understand them, the structure of the planning process must be examined.

1. Rapid Response Planning Process (R2P2)

Doctrinally, MEUs are given a warning order and expected to plan and be ready to execute a mission within six hours. The mission may be to secure an airfield, attack a critical target ashore, or even provide humanitarian assistance. Due to this variety, assignment to an MEU can be the most challenging tour any Marine might encounter in his or her career. Thus, the predeployment training received to execute these missions must be complex yet applicable to the changing threat. Never before has the U.S. seen the diversity of global threats as it does today. The CMC's directive seeks to put Marines in a position in which they can answer the call of duty from the sea when it comes. When the call comes, Marines will execute within six hours.

This six-hour constraint resulted in the development of the Rapid Response Planning Process (R2P2) shown in Figure 5. Once a mission is received, the Crisis Action Team (CAT) assembles, and the specifics of the mission are discussed. It is during this meeting that the MEU Commander provides his initial guidance to lead his Marines

through course-of-action (COA) development. Upon conclusion of this initial mission analysis, Marines go into their planning cells and develop between two to three possible responses to the threat.



Figure 5. R2P2 Planning Framework Used for Planning Amphibious Operations (From Joint Chiefs of Staff, 2001)

Approximately two hours after the warning order is issued, the MEU staff presents all COAs to the MEU Commander. Based on the updated enemy situation, each member of the MEU staff votes on which COA they think might best accomplish the assigned mission. The MEU Commander considers all inputs and then makes the final decision. Upon hearing the MEU CO's decision and guidance, staff members then return to their planning cells to conduct detailed preparation to execute the chosen COA.

Approximately two hours later, and four and a half hours after the order was issued, the MEU staff then briefs the entire ESG on the planned conduct of the mission—including departure from amphibious shipping, movement to target, mission execution and retrograde back to shipping. All portions of the mission are briefed in detail. Once all

key players understand the mission, they are dismissed for rehearsals. Normally, within 30-45 minutes, Marines depart the ship and begin their movement to the objective—keeping the entire R2P2 process well within the six-hour timeline goal.

2. Other Applications

Another training exercise conducted within the MEU predeployment training cycle is the Expeditionary Fires Exercise (EFEX). It provides training on combined arms at various points of the amphibious landing. During the initial phases of a landing, the combined arms effort is restricted to air assets and naval gunfire. Once Marines establish their presence ashore, they begin to utilize artillery and mortars in an integrated fashion with air and naval gunfire. Of all of the amphibious operations skills, this is by far the most complex. The complexity lies in the collaboration between numerous warfare specialties: aviators, artillerymen, and surface warfare officers, communicating and coordinating under battle conditions.

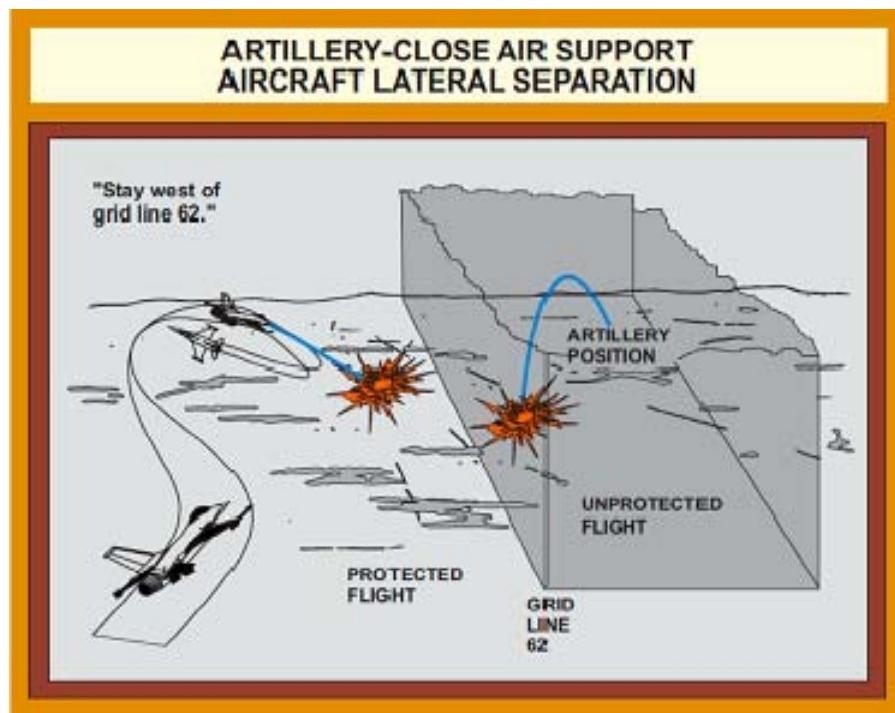


Figure 6. Depiction of Lateral Separation for CAS Missions (From Joint Chiefs of Staff, 2005)

A viewpoint-independent, three-dimensional (3D) visualization can be constructed for the complex mission shown as a 2D diagram in Figure 6. Such visualizations offer Marines who are planning to go ashore the ability to view the multiple methods used to de-conflict the strike assets attacking a single critical target. These missions might be animated and displayed above X3D Earth renderings. The animations of scenario actors can be driven using Simkit or even controlled by the user within a 3D web browser. This thesis demonstrates how to construct such visualizations, and further shows how they might be applied using EWD capabilities for group display.

H. THESIS ORGANIZATION AND RESEARCH METHODOLOGY

An iterative design approach was adopted to conduct the research efforts encompassed in this thesis. The goal is to immediately develop open source, visualization tools for an amphibious landing and then make those intermediate tools available for critique by prospective users. By testing intermediate products throughout development, one creates optimal conditions that enable development of the most user-friendly tools for training. This methodology differs from a spiral development approach in which users only get to test and provide feedback on the final design. By integrating young Marines and Sailors early on in the development process, and by, granting them some technical skills associated with virtual environments, the researcher hopes to encourage their buy-in and a sense of ownership.

This thesis also presents related work in the area of visualization and discusses some possibilities for collaboration. Chapter III covers the SunSPOT and its integration into the EWD. It shows development of the NPS TrackBot recommended to replace the current EWD ship models and the testing and evaluation conducted to determine appropriate control techniques. Chapter IV covers the uses of X3D Earth digital terrain and high-fidelity 3D models to create scenes applicable to amphibious training scenarios. Chapter V investigates the integration of digital holography into training at the EWD in order to accommodate both large staffs and small units for training. Chapter VI reviews the acquisition process in the Marine Corps and how this work fits into the JCIDS process. In addition, the researcher reviews amphibious readiness training requirements

in that chapter. In Chapter VII, the researcher makes overall recommendations on EWD layout and use of the technologies recommended. In addition, X3D models of the facility are presented for future collaboration to assist in acquisition decisions regarding the modernization of this crucial maritime training facility.

II. RELATED WORK

A. INTRODUCTION

Wargaming is a common thread through all of the projects described in this chapter and related to this work. Throughout history, wargaming has been a large part of military training. Examples are found as early as the 4th century through today. This chapter first provides a brief history of wargaming and then covers other research projects currently investigating enhanced visualization for training. For example, the BASE-IT team (comprised of researchers from NPS, University of North Carolina (UNC) at Chapel Hill, and the Sarnoff Corporation) is working on a revolutionary virtual sand table for use by Marine Infantry Squads. Their application of projected textures to depict buildings in a virtual environment produces a realistic, high-fidelity training table. In another example, Zebra Imaging is developing a cutting-edge dynamic holography video display tool. For years they have gained a great reputation producing static holograms, but as they explore combining dynamic models with holographic imaging, they are opening the door to numerous training applications. There are also two model repository development projects in progress, which are similar to the efforts described in Chapter IV of this work. All projects described in this chapter are considered for future utilization in the EWD modernization effort.

B. BRIEF HISTORY OF WARGAMING ON SAND TABLES

As mentioned above, a modernized EWD is expected to become a large sand table on which Marines may wargame a mission execution plan to attack an enemy from the sea. Military wargames have been around since the 4th century, as evidenced by the Chinese game “Go” (Gray, 1995). The game’s popularity spread quickly across East Asia but did not arrive in the West until the late 19th century (1995). A number of legends allude to how the game was created. Some believe Chinese Emperor Yao (2337–2258 BC) created the game to teach his son, Danzhu, balance and discipline (“History of Go,” 2009). Others believe Chinese warlords and generals created the game to map out future

military maneuvers and attacking positions (2009). No matter how it was created, many recognize its importance for training young soldiers in maneuver warfare.

For a long period of time, wargames were principally used for entertainment. This changed in 1811 when Baron von Reisswitz, a civilian war counselor to the Prussian court at Breslau, began to study the applications of wargaming to real-world military operations by creating a sand table. After seeing his initial demonstrations, two young Prussian princes requested a demonstration for the King (Gray, 1995). Although the King was impressed, the von Reisswitz sand table model failed to gain any momentum within the military. Von Reisswitz feared his idea would fall by the wayside.

About 10 years later, Baron von Reisswitz' son, Lt. George Heinrich Rudolf Johann von Reisswitz—now a Prussian Guard Artillery Officer—tried once again to display his father's sand table with some modifications (Gray, 1995). He used topographical maps and a rigid set of rules, which quantified the effects of combat (Gray, 1995). Prussian Prince Wilhelm was so impressed with the new wargame he recommended it to the Chief of the Prussian General Staff, General von Muffling. Reluctantly, General von Muffling scheduled a demonstration for his General Officers. On the evening of the demonstration, many were skeptical, but Lt. von Reisswitz was not dissuaded. He quickly requested that General von Muffling provide some special ideas for military maneuvers and also select two officers to serve as commanders of each side (Gray, 1995). The maneuvers commenced, and all observers began learning about maneuver warfare in a large-scale battle. The demonstration was recognized as a huge success after General von Muffling exclaimed, “This is not a game! This is training for war! I must recommend it to the whole army” (Gray, 1995, p. 1).

The excitement continued when Helmut von Moltke created a wargame club, the Kriegspieler Verein, in 1828 (Gray, 1995). As he promoted to the Chief of Staff of the Prussian Army in 1837, he continued to push for the usage of wargames for training. When employed as a large part of the training regimen, outstanding performance on the battlefield soon followed. The Prussian Army decisively defeated the French Army in the 1870-1871 Franco-Prussian War (Dunnigan, 2000). The world took notice and more interest in wargaming began to develop. The United States soon followed Prussia's lead

and created its own wargaming table in 1882 (Gray, 1995). This was the beginning of a long line of synthetic trainers used throughout U.S. history, and they have evolved as technology has improved.

The EWD is essentially a wargaming table on a very large scale. The Marine Corps is in a similar situation to von Reisswitz in trying to make the wargame/trainer more applicable to current training needs. Both enhanced 3D visualization and the gaming industry have advanced significantly within the last 10 years. Continued examination of past projects that leverage such advancements can provide helpful ideas and encourage new collaborations.

C. 3D VISUALIZATION PROJECTS

1. Behavioral Analysis and Synthesis for Intelligent Training (BASE-IT)

As mentioned earlier, the Office of Naval Research (ONR) is sponsoring a groundbreaking research to help prepare Marines for military operations in urban terrain (MOUT). One of the segments that constitute this research project was a creation of a virtual sand table that would be used to conduct both mission planning and After Action Review (AAR) for Marine squad maneuvers in a typical urban warfare environment. In order to provide more intelligent learning, the project will provide a play-back of a recorded training session with automated understanding of the performances exhibited on training range, but it will also seek to create a behavior synthesis capability. In other words, the system will be able to generate new (never recorded) performances “on-the-fly” and show Marines the consequences (or rewards) resulting from a different set of actions than those they performed initially in the MOUT environment. One of the training tools to be used to visualize that type of information (performances) is the Virtual Sand Table shown in Figure 7, which uses three projectors above a flat white surface. On the flat surface, multiple, scaled blocks (physical artifacts) are placed to depict buildings and obstacles within the MOUT facility. The projectors then project textures on the sides of the blocks—creating a three dimensional, small-scale MOUT facility representation that is inherently auto-stereoscopic in its nature (each viewer sees object as three-dimensional,

without the use of special stereoscopic glasses). This is a clear upgrade since flat imagery is used to project the area while the texture-enhanced blocks enable a full sense of the third dimension.

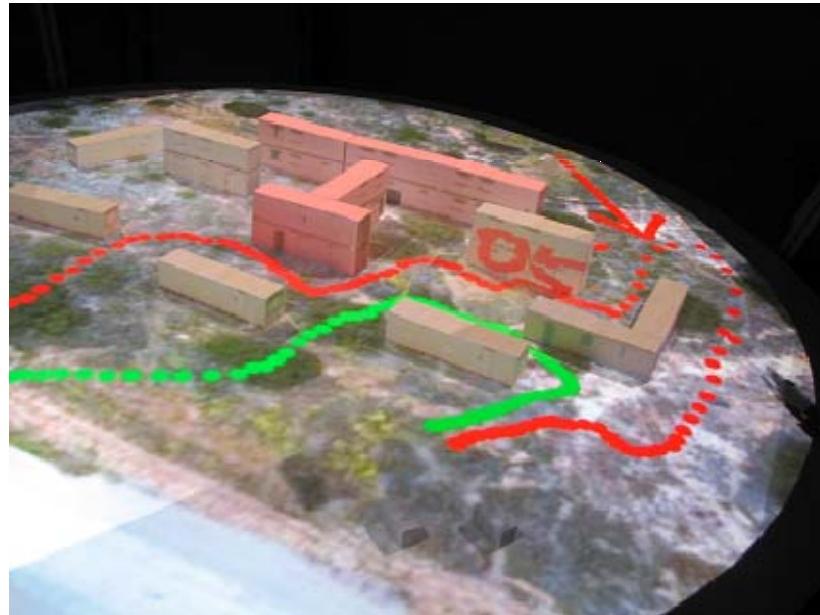


Figure 7. BASE-IT Table showing path planning in an Urban Environment

The Delta3D open-source game engine drives the visual display. This is where the BASE-IT work closely aligns with the EWD modernization. The animations created in Delta3D might further be used to show Marines' movements within the MOUT facility and to evaluate their performance. Also, additional artificial intelligence (AI) algorithms can be applied to the objects (individual Marines and groups of Marines) in this context to show other possible (future) maneuvers that have never been recorded and are generated "on-the-fly." This system has a potential to offer the most comprehensive learning. Since three projectors are used, it is possible to point and touch locations on the projected imagery during debriefing without the imagery being obscured with shadows, thus offering a more hands-on and user friendly feel for the training. Additionally, a touch pen called Magic Marker is available to the users to draw on top of the imagery to highlight specific locations, lines of sight or avenues of approach. This same feature does not exist in current EWD setup, and would be very much welcomed in its future upgrade.

The research is now entering its third year, and the progress made has been significant. With the successes already seen, there are definite applications of this technology to the EWD as it trains Marines in squad maneuvers. The concept of the virtual sand table has definite applications in the target area phase of an amphibious landing. Since the audience within the current EWD setup is on both the left and right side of the display table, visualizations must use flat X3D Earth imagery to ensure that both sides see the same scene. On a smaller scale, the BASE-IT Virtual Sand Table can augment the proposed animated scenes by creating a few target areas enhanced with blocks and projected textures. The team's prototype shown in Figure 8 has performed well in initial testing, and the EWD may be another facility to utilize the display concepts demonstrated by the BASE-IT virtual sand table.



Figure 8. The BASE-IT Virtual Sand Table Showing Overhead Projector and Situated Blocks

The primary limitation of the BASE-IT approach is that the visualization is confined to a single location, orientation and scale since the fixed blocks cannot move. However, the same display concepts are applicable to any dynamic scene (physical

artifacts moving), as long as the system knows how and where those objects moved on the surface. Further work is needed on combinations of multi-projector displays to provide coverage for a large area; this topic of tiled display surfaces is another domain in which different research team, including the researchers from BASE-IT project, have expertise. Despite the limitations of current renditions of Virtual Sand Tables, the BASE-IT approach provides interesting capabilities that can be applied within a larger EWD setting.

2. Digital Holography

Holographic imaging has gained some recognition over the last 10-15 years as a fantastic way to visualize terrain, complex hardware, etc. The leading developer of holographic technology in the United States is Zebra Imaging, Inc., based in Austin, TX. The company, founded in 1996, was created “to develop display technologies and products for 3-D visual communications” (Martin, Holzbach, Riegler, Tam, & Smith, 2008, p. 17). The company produces holograms for various real-world applications from real-time military planning (as seen in Figure 9) to system analysis.



Figure 9. Depiction of Zebra Imaging Hologram Used in Combat (From Zebra Imaging, 2009)

With overall success in the business world, holography quickly found applications in the military. Recently, Zebra Imaging and the Air Force Research Laboratory (AFRL) conducted a user study using holography to enhance Joint Terminal Air Controller

(JTAC) training, which is described in Chapter V (Martin et al., 2008). A research team from Texas State University in San Marcos, TX conducted another user study testing the effectiveness of holography in route planning for Special Weapons and Tactics (SWAT) teams (Fuhrman, Komogortsev & Tamir, 2009). The results were also encouraging. Holography can be considered a viable visualization option for the EWD when wargaming small unit actions at the objective after an amphibious landing. The application of holography to small units is also investigated in this work.

D. COMPUTER-BASED GAMING (SURFTACS VERSION 1)

The explosion of computer-based games in the entertainment industry has not gone unnoticed by those in the military training community. They are a low-cost, robust solution with the potential to train numerous military skills. In 2006, Lt. Ryan Ernst developed SurfTacs, a virtual naval surface tactics trainer. Using the open source Delta3D game engine, he created SurfTacs to address the growing need for comprehensive tactical training for surface warfare officers in the Navy. Since the latter half of the twentieth century, surface warfare officers used 24-foot wooden Yard Patrol (YP) craft for their ship handling training (Ernst, 2006). This was a relatively inexpensive way to give young officers the experience they need to operate aboard larger U.S. naval ships. The YP fleet was decommissioned in the mid-90s; soon the Navy transitioned to using Bridge and CIC Team Trainers to provide instructions (2006). Those trainers were successful, but the Navy still added the Conning Officer Virtual Environment (COVE) to train its officers (2006). Finally, the Navy began sending surface warfare officers to Marine Safety International (MSI) training centers located in San Diego, Norfolk and Newport (2006). Obviously, the Navy was making an effort to improve training, but as with most Services, the majority of the trainers went unused due to the high operational tempo that kept students occupied elsewhere. With this in mind, Lt. Ernst sought to create a desktop-based trainer easily deployable and available to all surface warfare officers.

SurfTacs provides training in six different division tactics commonly used in surface operations. Each maneuver displays communications from other ships maneuvering in the vicinity. In addition, communications are also received from other

sections of the ship—for example, the engine room and its crew’s reaction to a requested maneuver. Ernst’s work might contribute to this researcher’s investigation of replacing the EWD’s ship models. For example, the graphical user interface for the SunSPOT robots might be provided using SurfTacs’ tactical display. Collaboration with the Delta3D team to expand the available tactics within SurfTacs while incorporating the tactical movements of the SunSPOT ship models might make the EWD a more effective maritime trainer. Figure 10 shows the user interface for SurfTacs Version 1.



Figure 10. SurfTacs Version 1.0 Showing User Interface for Leap Frog Surface Tactic (From Ernst, 2006)

E. MODEL REPOSITORIES

1. BRL-CAD and Google Summer of Code 2009

The Army Research Lab (ARL) uses the Ballistics Research Laboratory-Computer Aided Design (BRL-CAD) software to create models for ballistic and electromagnetic analysis to predict survivability of combat vehicles. It was developed in 1983, released in 1984 and eventually became an open source project in 2004 (“BRL-CAD,” 2009). In the summer of 2009, ARL mentored five students through the Google Summer of Code (GSoC) project. This is a global program offering graduate and undergraduate students the opportunity to work on real-world software development projects over a three-month period. For their work, the students normally receive a

stipend and are required to share their work with fellow developers (“Google Summer of Code,” 2009). One of the ARL and GSoC projects closely aligned with this thesis was Elena Bautu’s work on the BRL-CAD’s “MoRe,” or model repository. Her goal was to create a common repository of BRL-CAD models allowing users to share and locate models required for their work (Bautu, 2009). Her project uses Drupal, which is “a free software package that allows an individual or a community of users to easily publish, manage and organize a wide variety of content on a website” (“Drupal,” 2009). Her efforts are similar to this work regarding the conversion BRL-CAD models into the X3D format. This same work was done with Army Model Exchange (AMEX) models for use in X3D Earth scenes. The AMEX models were created in BRL-CAD, converted to X3D files and modified to enable viewing across all available when browser. Future collaboration with the BRL-CAD team is possible to expand this work.

2. NPS Virtual Environments Resource Repository

The existence of a unified, comprehensive public resource of domain information has been long recognized as one of the instrumentals for a diffusion of reliable and consistent information in particular domain. Driven by that goal, Dr. Amela Sadagic and Dr. Don Brutzman have proposed the creation of “a public reference resource dedicated to the domain of modeling and simulation in virtual environments” at NPS (Sadagic & Brutzman, 2009). This repository would hold re-usable 3D models, research papers, video demonstrations, case studies, and multi-media files for use by a selected group of users. These users are expected to form an online community to encourage collaboration and shared learning. Such emerging capabilities provide good organizing principle for maintaining diverse EWD model assets.

F. OPPORTUNITY FOR THE NAVY

CAPT Mark Wooley, the Commanding Officer of the Naval Reserve Officer Training Corps (NROTC) at the University of San Diego (USD) and San Diego State University (SDSU), recently wrote an article critical of the Navy’s inability to effectively use gaming technologies to train Sailors. According to Wooley, the Army’s achieved a major success with *America’s Army*. “In November 2008, there were 9.5 million

registered players” (Wooley, 2009, p 36). Now, the Army is embarking on their second venture investing \$50 million dollars over a five year period to train soldiers in combat (2009). This leaves many to ask about the Navy’s plans to capitalize on these emerging technologies. Soon after *America’s Army* was released to the public, the Navy unveiled *Naval Training Exercise: Strike and Retrieve* (Wooley, 2009). It was deemed a failure, as it did not gain the same notoriety as *America’s Army*. It seemed too futuristic and had no real training value. Across the Navy, many share the same concerns as CAPT Wooley. The Navy really needs to get in the game, and the EWD modernization presents a major opportunity.

G. SUMMARY

This chapter first covers a brief history of wargaming. It then introduces some current wargaming tools such as the BASE-IT virtual sand table and Zebra Imaging’s dynamic and static holography. Both have possible applications to the EWD in possibly expanding its training to Marine infantry squads. Regarding model repositories, the BRL-CAD and NPS work may enhance similar work presented in this thesis. Further investigation is recommended for collaboration. Lt Ryan Ernst’s thesis work on SurfTacs is presented with a possible application to the EWD’s SunSPOT ship models. Finally, a reference to an article critical of the Navy’s current lack of use of gaming technology for training is presented to encourage increased collaboration between the Navy and Marine Corps on this modernization project.

III. APPLICATION OF ROBOTICS

A. INTRODUCTION

The first phase of this work was to improve visualization and control of amphibious ship models within the EWD leveraging the wireless communication capability within Sun's Small Programmable Object Technology (SunSPOT). Shown in Figure 11, this small lightweight device contains multiple capabilities including a radio transceiver and multiple high power pins capable of electrically driving a small motor; the dimensions of the unit are: 69.85 mm by 41.275 mm by 22.225 mm. These capabilities enabled the creation of small, robotic ship models intended for use in the EWD. Since the iterative design approach was applied to robot development, Marines assigned to the Defense Language Institute (DLI) were able to contribute to the overall design by making recommendations for the control interface. Their inputs are contained in Appendix B.



**Figure 11. SunSPOT from Sun Microsystems
(From SunSPOT World, 2009)**

B. PROJECT SUNSPOT AT SUN MICROSYSTEMS

SunSPOT's initial development began in 2003 when researchers at Sun Labs began working on wireless sensor networks. Quickly, they recognized the need for more

powerful sensor devices that were easier to program. Thus, in November 2004, they stopped their work to launch Project SunSPOT. In this project, they started from the ground up, and their wish list was extensive. In the end, they created a device containing an integrated radio transceiver, 8 tri-color light-emitting diodes (LED), 20 various input/output pins, a three-axis 2G/6G Inertial Sensor, and a Toshiba TPS851 light-to-voltage sensor (Sun Microsystems, 2006). With all of these capabilities, Sun released the SunSPOT to the public at large in late 2006. The response was enthusiastically positive. Sun Labs made development easy by posting numerous sample programs on their website at <http://www.sunspotworld.com>. This site was the main source of information for this work.

This technology also complies with the criteria discussed in Chapter I. First, it is open source. On java.net, the user community can gather to exchange system code, application frameworks, demonstrations and applications (SunSPOT World, 2009). The developers at Sun Labs continuously monitor the java.net site to standardize the usage of these devices across the community. With numerous tutorials and examples available online, the device can be considered relatively easy to use assuming a basic understanding of the Java programming language. Overall, it fits each of the three development guidelines set for this work.

C. SUN'S SMALL PROGRAMMABLE OBJECT TECHNOLOGY (SUNSPOT)

1. SunSPOT Development Kit

The SunSPOT Development Kit comes with two SunSPOTs, one base station, a wall-mount bracket and an eSPOT module adapter (Sun Microsystems, 2006). On the SunSPOT, there are two circuit boards within the plastic outer shell: the eSPOT main board and the eDemo board. The base station only has the eSPOT main board. The main board contains the main processor, memory, power management circuit, and the 802.15.4 radio transceiver with antenna, battery connector, and daughter board connector (Sun Microsystems, 2006). Main board communication to the SunSPOT is via a USB, shown as #4 in Figure 12. Through the USB the SunSPOT Development Kit (SDK) containing the functional methods and the jar files used to program the SunSPOTs can be loaded.

The USB port is also critical for the base station as its main power source connection. Since the base station is not equipped with its own battery, it only operates when powered by a desktop or laptop computer.



Figure 12. SunSPOT USB Connection Used to Load SDK and Recharge Internal Battery (From SunSPOT World, 2009)

The internal battery within the eSPOT “is a 3.7V 720mA·h rechargeable lithium-ion prismatic cell” (Sun Microsystems, 2006, p. 9). It can be easily charged in one hour via the USB and used to power small input devices such as sensors. For example, for this work the internal battery was used to power a small sonar to demonstrate autonomous vehicle control. The battery power was accessed via one of the input/output pins on the eDemo board. Unfortunately, only one device is able to draw power at any one time, so additional power sources have to be added to accommodate multiple input devices if needed. One other point regarding usage of the SunSPOT battery is that its primary purpose is to power the device itself. Drawing power for additional input devices significantly reduces its battery life. During prototype development, efforts were made to avoid placing additional demands on the SunSPOT battery.

For this work, the most important component on the main board was the integrated radio transceiver, the TI CC2420 (Sun Microsystems, 2006). “It is IEEE 802.15.4 compliant and operates in the 2.4GHz to 2.4835GHz ISM unlicensed bands” (2006, p. 12). The ISM bands were originally reserved for use within industrial, scientific, or medical matters, not for communication (“ISM band,” 2009). Over time, its high reliability made it applicable to research tasks such as this. Although there is a

possibility for some interference in communications, none was noticed during the development of the SunSPOT robot at NPS.

The overall concept for this work was for a user to manipulate a hand-held SunSPOT to produce acceleration data on the x-, y-, and z-axis. That data is passed to a SunSPOT device mounted on the robotic vehicle. The virtual machine on the SunSPOT can then process the data and energize the appropriate high-power pins on the eDemo board to drive the engines. This was all done within a 10-meter communications area.

2. eDemo Board

For users of the SunSPOT, most work is developed using the eDemo board. “Along the top of the eDemo board is a row of eight tri-color (red-green-blue) LEDs” (Sun Microsystems, 2006, p. 18). These were especially helpful when the researcher was trouble-shooting code for the performance of a specific action. With the LEDs, a developer can visually see how the code is operating by illuminating specific LEDs as data packets are sent and received. “Below the LEDs are two tactile pushbuttons, SW1 and SW2” (2006, p. 18). For this work, the buttons were used to control vehicle left or right turns by setting the high power pins to high or low based on switch position. Below the switches is “the ST Microsystems 3-Axis 2g/6g Inertial Sensor” (2006, p. 20). For the SunSPOT’s orientation, the z-axis is perpendicular to the device surface; the y-axis is parallel with the device surface and perpendicular to the row of LEDs, and the x-axis is parallel with the row of LEDs. The accelerometer data is used in this work to control forward and reverse movement of the NPS prototype robot. Users can simply rotate the SunSPOT about the x-axis to move the robot in the forward or reverse direction. Left of the accelerometer is the Toshiba TPS851 light-to-voltage sensor (Sun Microsystems, 2006). This capability was used to start and stop the vehicle during testing. If the luminance was above a specific level, the pins controlling the motor were set high or low. The peak sensitivity of the light sensor is 600nm (Sun Microsystems, 2006). Finally, below the light-to-voltage sensor are twenty input/output connector pins. These allow for the collection of data from external sensors and also the precise placement of power on mounted motors. The Vh pin powers all of the high-power output pins (H0-H3) and

requires a battery input of between 4.5V to 18V (Sun Microsystems, 2006). The D0-D3 pins can collect data from additional sensors added to the prototype. The rightmost pins on the eDemo board are grounds used for the battery sources. Overall, the eDemo board described above and shown in Figure 13 has numerous capabilities relevant to the application of robotics to the EWD.

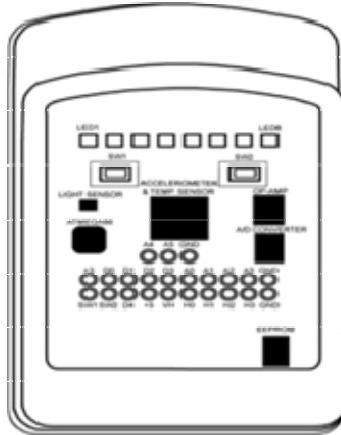


Figure 13. SunSPOT eDemo Board Layout
(From SunSPOT World, 2009)

D. CONSTRUCTION OF MOBILE ROBOTS AT NPS

The equipment required to construct an EWD proof of concept for the amphibious display was five NPS prototype robots, two Systronix TrackBots, seven robot user controllers, and 2 wireless access points (SunSPOT base stations) for the communications relay. On a smaller scale, this section specifically covers the overall development process for the first prototype robot and its controller. It concludes with design recommendations received from a user study conducted during development.

1. Hardware Required

Since the usage of the EWD is expected to increase after modernization, construction hardware needs to be easily accessible and durable. Tamiya Corporation produces model parts that comprise a large portion of the robotic vehicles created. For the chassis, two (2) Tamiya universal plates, four (4) 6-32 bolts of 2 inch length, and three (3) 9V battery holders were used. For the motors, a Tamiya Twin Engine multi-gear motor, two (2) motor controllers, two (2) Tamiya Wheel Sets, and a single Tamiya ball

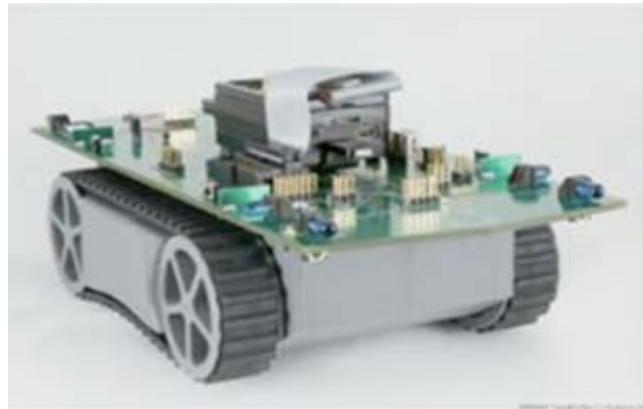
caster were used. The details of how all these parts were utilized are described in the next section. The overall brain of the robotic vehicle was the SunSPOT virtual machine described previously. An economical solution for EWD modernization was required, so constructing robots in labs at NPS offered the best value. Table 1 shows the total cost for five developmental robotic vehicles and two Systronix TrackBots for emplacement within the EWD.

Table 1. Cost for Seven Robots Used in Maritime Display Concept for EWD

Item	Number	Cost per Item	Total Cost
Systronix TrackBots	2	\$537	\$1074
Systronix TrackBot Hex Files	1	\$2	\$2
Systronix TrackBot Schematics	1	\$20	\$20
Tamiya Twin Motor Gearbox	5	\$12	\$60
Tamiya Battery Holder	5	\$6	\$30
Tamiya Universal Plate Set	5	\$9	\$45
LV-MaxSonar EZ-4 High Performance Sonar Range Finder	1	\$250	\$250
Solarbotics L293D Motor Driver Electronic Kit	10	\$130	\$130
Total			\$1611

2. Ship Model Design

The most difficult aspect of this research was finding a design offering smooth movement while retaining the capability to hold the weight of a balsa wood ship hull, three 9V batteries, and the SunSPOT device. Initially, testing was conducted with the Systronix TrackBot, which is a capable vehicle. However, at a cost of approximately \$600 per vehicle, this option was not as cost-effective. However, to allow for comparison, two of Systronix vehicles were purchased and tested in the proof of concept constructed at NPS. The Systronix design shown in Figure 14 was used as a guide for the NPS prototype ship model.



**Figure 14. Systronix TrackBot with Mounted SunSPOT
(From Systronix, 2009)**

Construction on the independent NPS prototype began by placing the tracked wheels onto the Tamiya universal plate. The goal was to place the SunSPOT and all necessary batteries onto that plate, expecting everything to fit. Since the universal plate is only 160 mm by 60 mm, space for hardware was extremely limited. The vehicle also began to get heavy with the addition of the SunSPOT and two 3V batteries. In the first test, a 3V battery failed because it did not provide enough power to turn the tracked wheels. A 9V battery then replaced the 3V battery. At this point, the battery requirements changed and the usage of tracks was abandoned for wheels. A wheeled design shown in Figure 15 offers significantly less friction, allowing for greater weight-bearing capacity. With these modifications, re-testing began. The 9V battery turned the motor smoothly with significantly more power. It then became the primary power source.



Figure 15. Initial Front Wheel Drive Version of the NPS TrackBot

A front wheel drive with a similar rear wheel design was selected. During testing, this seemed to be a good design at first because movement in forward and reverse

directions was smooth and consistent. However, when turning, the vehicle encountered significant slipping because the wheels had no rotation capability. Since the turning performance was so poor, a small wheel with ball bearings was then considered to replace the rear wheels. This modification performed well at first, but placing a wheel at the exact same height as the front wheels was difficult. Also, the ball bearings periodically became stuck, causing the robotic vehicle to inadvertently turn. Unfortunately, the power of the motor was unable to overcome the friction caused by stuck ball bearings. Some testing was possible at this point, but another modification was necessary.

The inspiration for the next modification was the usage of a single wheel similar to the design on a “tail dragger” aircraft shown in Figure 16. This was expected to be the final change, but during testing, the same issue arose as with the ball-bearing wheels: the single wheel got stuck, and the motor was unable to overcome the friction. Finally, the Tamiya ball caster was found and added to the vehicle.



Figure 16. NPS TrackBot “Tail Dragger” Version

Shown in Figure 17, the ball caster was placed in the rear of the vehicle and, as expected, it performed flawlessly. Under the power of the small Tamiya motor, the ball caster smoothly moved forward and in reverse. More importantly, it also precisely turned left and right. With this successful test, the next step was to select a motor controller to smoothly apply power to the engines based on inputs from the SunSPOT.



**Figure 17. Tamiya Ball Caster used to replace the “Tail Dragger” Wheel
(From Tamiya, 2009)**

3. Motor Controller

The motor controller served as the link between the engines and the SunSPOT. All four of the high voltage pins on the eDemo board were used to send power to the motors through the motor controller. Each vehicle had two. Both drew power through the V_h pin to send voltage to the engine, depending on a high or low pin setting. Thus, another power source was needed to energize the V_h pin on the SunSPOT. Since the V_h pin required 4.5V to 18V, the SunSPOT battery at 3.7V was not an option (Sun Microsystems, 2006). A third 9V battery needed to be added, but there was no more space on the universal plate. To accommodate, the chassis was redesigned slightly to make room for the SunSPOT and three 9V batteries. An additional universal plate was added creating a two-tiered design. The three 9V batteries were on the lower tier and the SunSPOT remained on the upper tier. The sonar was also added to the upper tier with additional space to add three more sonars if required.

During initial testing of this two-tiered design, a significant amount of heat was generated that melted some of the motor controllers. To dissipate the buildup, heat sinks were added to both motor controllers. Heat sinks are simply a small piece of aluminum added with some heat glue to act as a radiator dissipating heat into the air. Once added, they attached to both motor controllers and the universal plate. Heat sinks ensure continuous operation of the motor controllers. At this point, the prototype vehicle was complete as seen in Figure 18 and control techniques had to be developed.

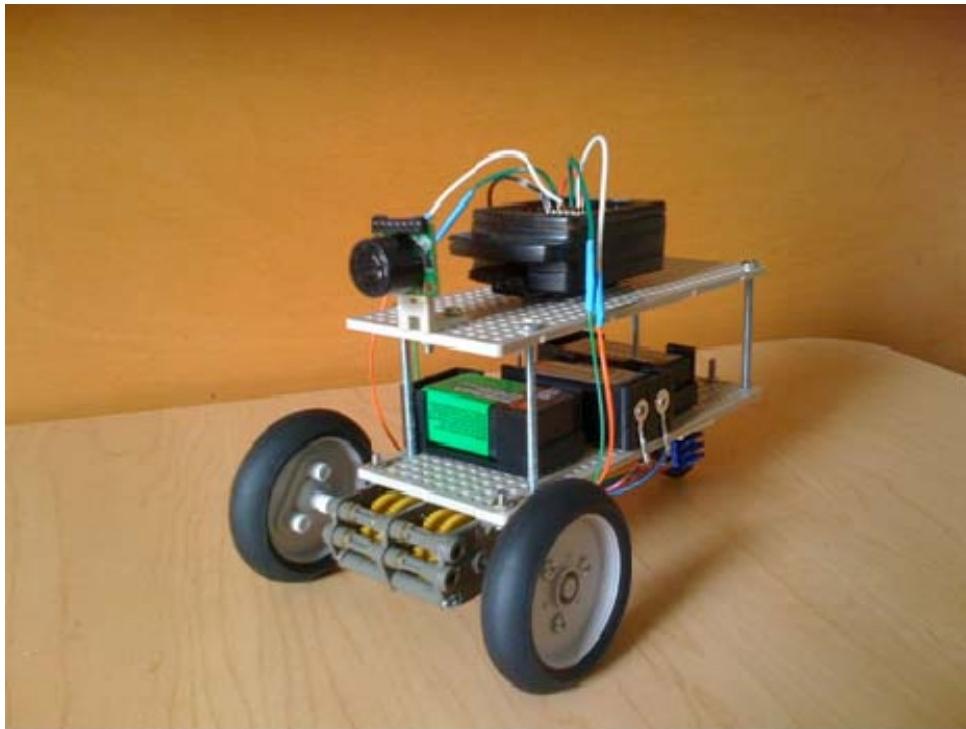


Figure 18. Final Version of NPS TrackBot

4. Control Techniques using SunSPOT

Because there are multiple options to control the prototype, the requirements to support the EWD were considered. The first goal was to have ships move in a predetermined sequence and stop on command. Second, since consideration was given to making the EWD a training device for real-world operations, having a specific ship's operations staff control their own ship models within the maritime display was more interesting. In short, the goal was to make the EWD interactive.

Using the radio transceiver embedded within the SunSPOT, the first step was to pass acceleration data based on a user's rotation of a hand-held SunSPOT. Detecting changes in rotation in the x and y directions, the hand-held SunSPOT can send data to the chassis-mounted SunSPOT to control the movement. The first challenge in developing this code was to make a connection between both SunSPOTS on a specific communications port. In the code shown in Figure 19, a broadcast port is opened between two SunSPOTS. With this port opened, data packets containing x and y direction acceleration data can be passed.

```

public void startReceiverThread() {
    new Thread() {
        public void run() {
            String tmp = null;
            double tility = 0;
            double tiltx = 0;
            RadiogramConnection dgConnection = null;
            Datagram dg = null;
            try{
                dgConnection = (RadiogramConnection)
                    Connector.open("radiogram://:37");
                dg = dgConnection.newDatagram(dgConnection.getMaximumLength());
            }catch (IOException e) {
                System.out.println("Could not open radiogram receiver
connection");
                e.printStackTrace();
                return;
            }
        }
    }
}

```

Figure 19. Java Code to Open a Broadcast Port for Communication

Passing two forms of data proved to be somewhat difficult since it required splitting of the data strings once received by the chassis-mounted SunSPOT. The code shown in Figure 20 was able to receive the acceleration data and sort it into a list of x and y acceleration values.

```

while(true) {
    try {
        dg.reset();
        dgConnection.receive(dg);
        char colon = 58;
        tmp = dg.readUTF();
        System.out.println("Received: "+tmp+" from "+dg.getAddress());
        String[] accelinfo = Utils.split(tmp, colon);
        System.out.println(accelinfo[0]);
        double tily = Double.parseDouble(accelinfo[0]);
        double tilx = Double.parseDouble(accelinfo[1]);
    }
}

```

Figure 20. Code to Create a List of Acceleration Data from Hand-held SunSPOT in x and y Directions

Once the data was sorted, conditionals were used to determine the required pin settings to operate the motors. Notice that the code displayed in Figure 21 checks the acceleration value and then sets the high voltage pins appropriately with the setHigh or setLow methods.

```

// Move forward straight
if (accelFB > 0 && accelLR == 0){
    outPins[EDemoBoard.H0].setHigh();
    outPins[EDemoBoard.H1].setLow();
    outPins[EDemoBoard.H2].setHigh();
    outPins[EDemoBoard.H3].setLow();
    System.out.println("TrackBot moving forward.");
}

// Turning right
if(accelFB > 0 && accelLR < 0){
    outPins[EDemoBoard.H0].setHigh();
    outPins[EDemoBoard.H1].setLow();
    outPins[EDemoBoard.H2].setLow();
    outPins[EDemoBoard.H3].setHigh();
    System.out.println("TrackBot is turning right.");
}

// Turning left
if (accelFB > 0 && accelLR > 0){
    outPins[EDemoBoard.H0].setLow();
    outPins[EDemoBoard.H1].setHigh();
    outPins[EDemoBoard.H2].setHigh();
    outPins[EDemoBoard.H3].setLow();
    System.out.println("TrackBot is turning left.");
}

// Move backwards
if (accelFB < 0 && accelLR == 0){
    outPins[EDemoBoard.H0].setLow();
    outPins[EDemoBoard.H1].setHigh();
    outPins[EDemoBoard.H2].setLow();
    outPins[EDemoBoard.H3].setHigh();
    System.out.println("TrackBot is moving backwards.");
}

```

Figure 21. Move Robot Based on Rotation of Hand-held Device

E. USER STUDY

1. Institutional Review Board (IRB) for the Protection of Human Subjects

In accordance with NAVPGSCOLINST 3900.4, authorization to commence the SunSPOT user study was requested through the NPS IRB (NAVPGSCOLINST 3900.4, 2002). The board reviewed the request and quickly authorized the conduct of the study although it was not required. Since the focus of the study was on physical devices vice human subjects, there was no threat posed to the subjects participating. However, to ensure compliance with the Department of the Navy's Human Research Protection Program (DON HRPP), this study was conducted as if IRB approval was required. All documents included the signed Informed Consent forms and Questionnaire responses will be stored at the MOVES Institute at NPS.

2. Hypothesis

With the ship model completely constructed, a wireless control interface had to be selected for recommendation for the EWD. Conducting a user study gave an opportunity to allow others not involved in the development to operate the ship model and provide detailed feedback on design and control implementation. There were two interfaces compared in this study. First, the SunSPOT itself with the embedded accelerometer was evaluated. Code for this interface is described above. A second option is a graphical user interface (GUI) shown in Figure 22 that can be displayed on a laptop or desktop computer. For this option, data is passed through a base station controlled by mouse selections on the displayed interface. The end state of this study is for a specific user interface to emerge as the preferred control device for the use in the EWD.

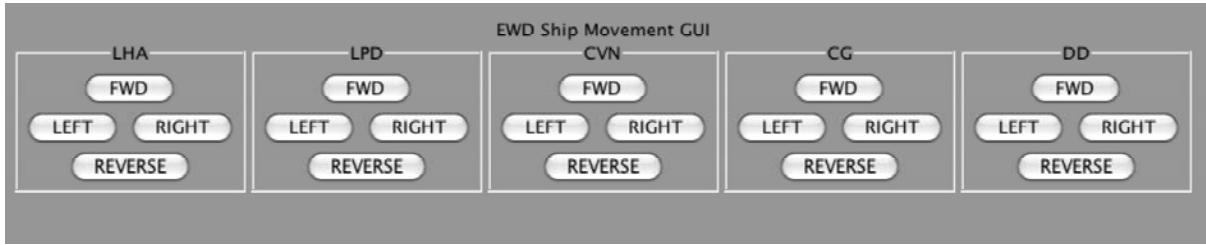


Figure 22. GUI used to control NPS robots during User Study

The hypotheses for this study are listed below.

H0: There is no difference between the SunSPOT interface and the GUI interface in controlling the NPS TrackBot.

H1: This is a difference between the SunSPOT interface and the GUI interface in controlling the NPS TrackBot.

3. Experimental Setup and Procedures

The experiment was divided into two segments and subjects were randomly selected to control the vehicle with only one of the user interfaces. In one segment, the subject was seated at a desk in front of the movement area with a laptop computer displaying 4 buttons (forward, reverse, left and right) to control robotic movement. At the beginning of each course, a verbal signal was given to begin driving the small robotic

vehicle through the prescribed course. In order to navigate, the subjects used a mouse to select buttons on the GUI as needed to drive the vehicle. Once the vehicle reached the destination point movement was stopped and the subject verbally declared completion of the course. This sequence was repeated for each of the three courses. Upon completion of all courses, the subjects asked to fill out the questionnaire on the graphical user interface.

In the other segment, the subject controlled the small, motorized robot using the SunSPOT device. To start, the subjects stood in front of the movement area holding the SunSPOT in the palm of their left or right hand. At the beginning of each course, a verbal signal from the instructor was given to begin driving the small robotic vehicle through the prescribed course. To move the small robotic vehicle, the subject had to rotate the SunSPOT device in their hand. Once the vehicle reached the destination point, vehicle movement was stopped and the subject declared completion of that course. This sequence was also repeated for each of the three courses. An example of one of the maneuver courses is shown in Figure 23. Upon completion of all courses, the subjects were asked to fill out the questionnaire on the SunSPOT device as well.

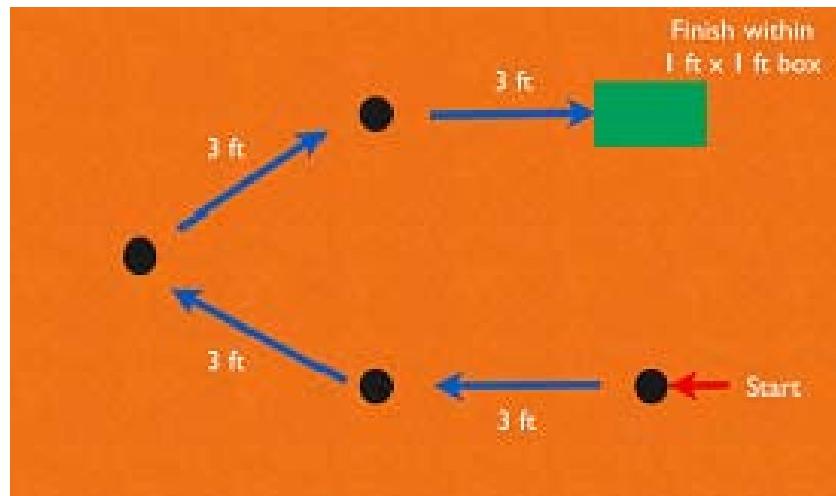


Figure 23. Example Maneuver Course used for both methods of control during User Study at DLI

4. Participants

The subjects for this user study were Marines assigned to the Defense Language Institute (DLI) at the Presidio of Monterey. Twenty-four Marines with ranks ranging from Private First Class (PFC) to Sergeant were scheduled to participate by the Marine Detachment Executive Officer in 20-minute blocks. During their specific time, they were randomly given one of two interfaces to use to control the NPS TrackBot. Some of the Marines had already completed the language curriculum, while others were waiting to start their studies. The majority of the Marines were experienced using computer-based games and most reported daily use of GUIs on their personal computers. One participating Marine is shown in Figure 24.



Figure 24. DLI Marine controlling NPS Robot through Maneuver Course During User Study

5. Results and Discussion

Once the Marines completed all maneuvers, they were asked to complete a short questionnaire, which can be found in Appendix B. The questionnaires asked the subjects to quantitatively rate their selected interface's level of control, intuitiveness, and difficulty to operate. For level of control, Marines were asked to respond on a scale of 1-5 how accurately their inputs matched the vehicle's movements. (Note: 1 was the lowest, 5 was the highest). In addition, they were asked to provide comments regarding their

overall impression of design and controllability. Those comments received were considered, and some adjustments were made to the source code driving the interfaces.

To assess the objective data collected in the study (subjects' performance), a two-sample t-test to compare the difference between the two mean responses was conducted. The data contained in Figure 25 was used to calculate the P-value. In this case, the P-value was 0.15. Thus, if 1000 responses for level of control were recorded, one hundred and fifty would have differences similar to the observed mean difference calculated for this experiment. This is not exceedingly rare; therefore, the null hypothesis was not rejected. There is no difference between the SunSPOT and the GUI interface. The responses for the level of control on both interfaces were almost identical. The GUI had a slightly better level of control with an average of 3, while the SunSPOT device had an average response of 2.6. Looking at the box plots and standard deviation shown in Figure 25, the GUI seemed to have a wider range of responses with a standard deviation of 0.738, which was slightly lower than the SunSPOT at 0.565. The data shows that both interfaces were effective, but neither seemed to emerge a significantly superior to the other.

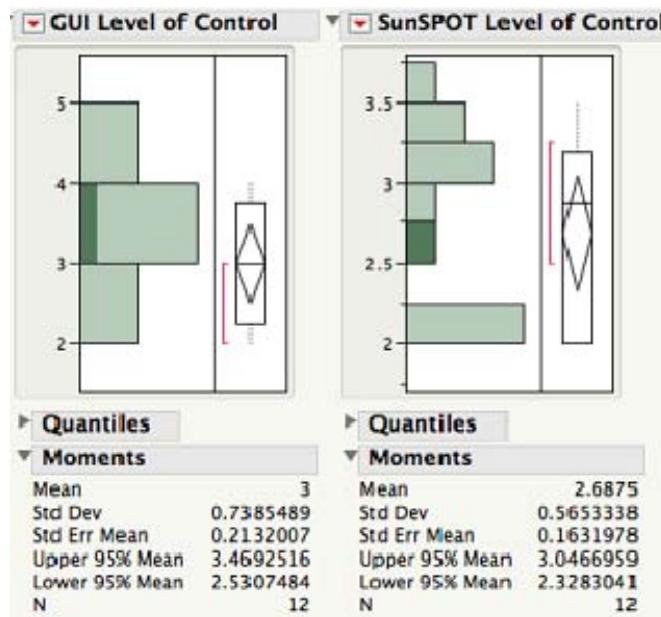


Figure 25. SunSPOT GUI Level of Control Box Plots Showing Marines Preferred GUI over SunSPOT (SS)

For the level of difficulty, the Marines were also asked to rate how challenging it was to navigate through each course using the specific control device. Again, a scale of one to five was used with one being difficult and five being easy. This data showed that the GUI was slightly easier to use with a 3.33 average response, slightly better than the SunSPOT's 2.75 average response. These results were also not statistically significant as shown by the box plots in Figure 26. Again, the null hypothesis was not rejected based on this data.

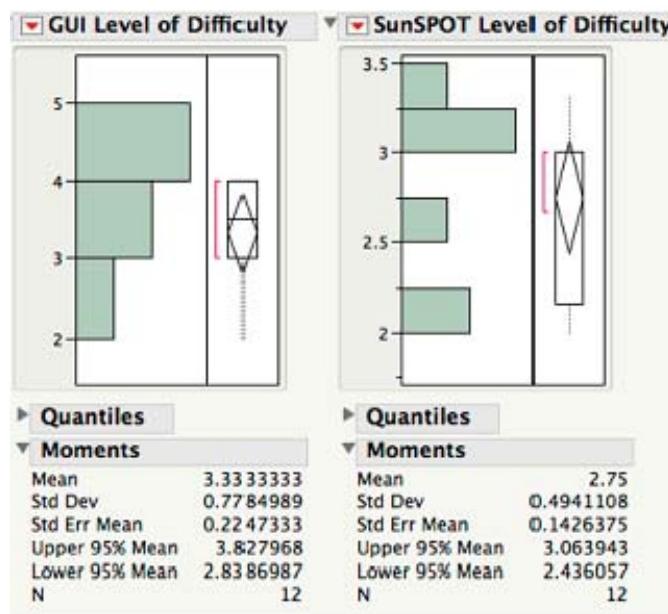


Figure 26. SunSPOT GUI Level of Difficulty Box Plots showing Marines has slightly more difficulty using the GUI over the SunSPOT (SS)

Although the Marines were only scheduled for 20-minute blocks to complete the three courses, most continued to stay and observe the study. Once all were complete, they discussed the interfaces at length. They were enamored with the technology and anxious to be involved with the development process. This was a critical observation and really showed the technical proficiency of today's entry-level Marine. The most interesting suggestion from discussions at the completion of the study was regarding the feasibility of combining the benefits of the GUI with the benefits of the SunSPOT. Marines seemed to prefer the freedom to walk around the display area given with the SunSPOT over the dependency on a laptop to operate the GUI. One suggestion was to use the two switches

on the SunSPOT eDemo board to control left and right turns. Marines were having difficulty controlling turns using the SunSPOT, because there seemed to be some latency in the passing of the acceleration data. On the other hand, Marines using the GUI had almost no trouble controlling turns in either direction. Considering this, source code shown in Figure 27 was developed to implement this suggestion.

```

while(true) {
    try {
        dg.reset();
        if (sw1.isOpen() && sw2.isOpen()){
            dg.writeDouble(accel.getTiltY());
        }
        if (sw1.isClosed()){
            dg.writeDouble(LEFT);
        }
        if (sw2.isClosed()){
            dg.writeDouble(RIGHT);
        }
        dgConnection.send(dg);
        System.out.println("Broadcast is going through");
        System.out.println("We're controlling the TrackBot!!!");
    } catch (IOException ex) {
        ex.printStackTrace();
    }
    Utils.sleep(500);
}

```

Figure 27. Java Code showing Switch Listeners for User Turn Inputs

6. Future Work

Initial testing with the modification above has been successful, but an additional user study needs to be conducted to definitively recommend usage of the SunSPOT device as the control interface for the EWD ship models. The next user study must integrate more difficult maneuver courses to test the switch modification. In addition, more subjects must participate in the next study to obtain more recommendations for development. The iterative design approach showed its benefit in this study for the development of the NPS TrackBot.

F. ADDITIONAL PROTOTYPES

1. Application of Other Capabilities

During research, autonomous control was considered to create threats within the maritime display. The code for an AutoTrackBot uses range data from a mounted sonar

and processes it to avoid collisions. The NPS TrackBot is set to turn when it reaches within six inches of an obstacle. The obstacle might be anything from a wall to another robot. The code in Figure 28 shows how data was retrieved from the sonar.

```
public void startReceiverThread() {
    new Thread() {
        public void run() {
            while (true) {
                sonarPulse = mother.getPulse(sonarPin, true, 1000);
                System.out.println("Pulse = " + sonarPulse);
                range = sonarPulse / 147;
                System.out.println("Range = " + range);
            }
        }
    }.start();
}
```

Figure 28. AutoTrackBot Code for Collecting Sonar Data and Converting it into Inches

Once the sonar return is measured, it is converted into a factor that can be easily understood. In this instance, inches were used. This value was then checked for proximity to an obstacle. If an obstacle was within six inches of the TrackBot, it turns randomly left or right. Once on a new heading, the sonar would continue to take data to avoid another possible collision.

Another interesting aspect of the AutoTrack was the usage of the onboard light sensor. In this case, to start the TrackBot, it only moved if it sensed at least 600ns of light. Once the light was sensed, it automatically moved while collecting sonar data. The forward motion continued until an obstacle was encountered or less than 600ns of light power was sensed. The code in Figure 29 shows how the light data was obtained and the sequence of conditionals that were used to control the AutoTrack based on light power.

```
try {
    lightIndication = lightSensor.getValue();
    System.out.println(" " + lightIndication);
} catch (IOException ex) {
    ex.printStackTrace();
}
leds[1].setOn();
leds[1].setRGB( 0, lightIndication / 3, 0 );
```

Figure 29. AutoTrackBot Collection of Luminance from Light Sensor on eDemo Board

2. Possible Applications to EWD

The sonar onboard the TrackBot offers many options within the EWD—the most obvious being collision detection. However, this may not be required if the EWD becomes interactive with actual ship staff members controlling their specific ship. They can easily avoid collisions and move their ships safely throughout the maritime display. The use of the light sensor is a bit more intriguing because it might also be used for small boat attacks. By shining a point light on a ship model with the AutoTrack code installed, a small boat attack can be simulated by moving directly towards any of the ship models within the maritime display. This type of simulation is a significant upgrade to the current EWD and offers some type of threat reaction that was not completely scripted. In addition, using the spotlight can focus audience attention on the small boat attack and the subsequent reaction to the threat.

G. PROPOSED USAGE AND OBSERVER INTERACTION FOR EWD

The goal for the modernized EWD is to create a more interactive experience. In the current state, the audience only watches the movements and the scenarios follow a script. This is good for initial training; however, continued use of the EWD needs to be the goal since it may become a training facility that meets the CMC's goal of improved amphibious operations expertise. Marines and Sailors learn and retain more regarding the intricate planning and coordination required within an amphibious assault if they are required to participate. Although the participation may be minimal, it still makes the training more interactive. The overall goal is improve amphibious readiness, and a new interactive maritime display may be able to do that.

H. CONCLUSIONS

The application of SunSPOTs to upgrade the EWD can improve the current display tremendously. The current pulley system does not encourage any user interaction. It is solely a demonstrator. Using robotics can significantly upgrade the current ship display by making it more interactive and relevant to amphibious training requirements,

which will be discussed in Chapter VI. For example, with some of the capabilities discussed in the Other Prototypes section, integration of surface tactics to react to small boat attacks is now a reality.

I. SUMMARY

This chapter presents the SunSPOT as an open source wireless communication system applied to the EWD to create moving ship models to replace an outdated technology currently in place. The overall development and testing is presented in detail. Finally, an additional prototype is shown to encourage future exploration with these devices.

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IV. ANIMATED X3D TERRAIN AND VEHICLE DISPLAYS FOR TRAINING

A. INTRODUCTION

The second phase of this work was to address the fixed terrain display in the current configuration of the EWD. This chapter covers how to combine enhanced 3D terrain and high-fidelity 3D models to create X3D scenes. Using the functionality within X3D, models within these scenes can be animated to produce compelling visualizations applicable to military training. X3D Earth and the Army Model Exchange (AMEX) model repository are the two tools recommended for use in the modernized EWD.

B. METHODOLOGY

This segment presents a step-by-step process to create animated scenes by placing dynamic Army Model Exchange (AMEX) models into X3D Earth imagery. To create these scenes, source imagery from the National Geospatial Intelligence Agency (NGA) was first processed by Global Mapper and then translated by Rez, a Java-based, open-source, geospatial processing software. Rez is a framework for translating geospatial, gridded data into different formats, including images and multi-resolution models for X3D web browsing (Thorn, 2007). Once the imagery is processed, high fidelity 3D models from the AMEX repository are then exported for use within X3D Earth scenes. These models previously created in BRL-CAD are not directly viewable in the Xj3D browser, the first recommended browser for use with X3D Earth. Thus, X3D-Edit 3.2, an open-source editing tool, is used to make the required modifications on the models to enable viewing. With the use of X3D-Edit 3.2, over 110 models were exported, modified, and placed into a model repository maintained at NPS allowing users to emplace and animate them in X3D Earth scenes, depending on specific training objectives. The users of these animations are Marines and Sailors assigned to Marine Expeditionary Unit (MEU) training in the EWD.

C. X3D EARTH MODELS

For this work, obtaining the best real-world geospatial information was most critical in order to provide relevant 3D training animations to Marines. X3D Earth was selected because it complies with the recommended criteria outlined in Chapter I. First, X3D Earth has an open International Organization for Standards (ISO) specification. The development of X3D Earth is guided by the X3D Earth Working Group. Its vision is to make it easier to create and use 3D spatial data (X3D Earth, 2009). That vision is a hallmark for this work with the end state of Marines being able to create scenarios for training. The following sections outline the process of turning imagery into a relevant training tool to ultimately show that X3D Earth also meets the ease of use criteria.

1. Source Imagery

High-resolution optical imagery sources are now widely available, but they come in different levels of resolution (Yoo & Brutzman, 2009). The first step in this work was selecting a readily available source of high quality imagery. The National Geospatial Intelligence Agency (NGA) was immediately selected. As illustrated in Figure 30, the NGA is engaged in a contractual relationship with three commercial imagery providers (Digital Globe, Space Imaging and OrbImage) that provide high-quality imagery to all federal government employees via NGA's Web-based Access and Retrieval Portal (WARP). The portal can be accessed at <https://warp.nga.mil>. Once imagery is collected, it is placed in the Unclassified National Information Library (UNIL) Commercial Imagery archive. The WARP then provides a simple, intuitive user interface to retrieve data from the UNIL.

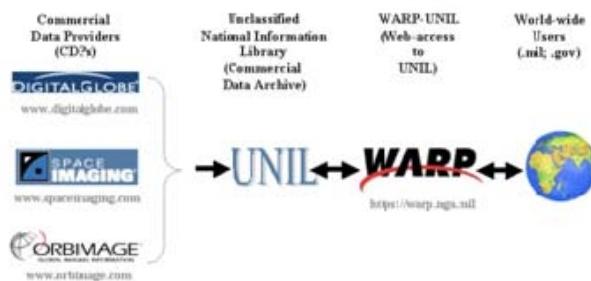


Figure 30. Imagery Flow from Commercial Data Provider (CDP) to Federal Government Users (From Kozma, 2005)

The WARP search query produces a list of all imagery available within a specific latitude-longitude range. Once available, the image files can be downloaded via the hypertext transfer protocol (http) or the file transfer protocol (ftp). The downloaded imagery is in the National Imagery Transmission Format (NITF) (e.g., .ntf file extensions).

2. Terrain-tile Production Chain

The NITF format is viewable in Global Mapper Version 10, which compresses the NITF file into the Joint Photographic Experts Group (JPEG) format. The JPEG file can then be converted into a JPEG World file (e.g., .jgw), which is simply a JPEG file in a geo-referenced format. Finally, based on the location of the imagery, Global Mapper can also download the required elevation data within the image in an ASCII file format, which is a text file with geo-referenced elevation data. Once these data files are produced, an image database of multiple levels of detail (LOD) must be created to allow multiple viewing perspectives in the Xj3D browser. To create this data, the Rez application is used. Rez includes the SmoothImageSlicer program, which takes an image and slices it into smaller parts to produce a multi-resolution tree of smaller images at a specified resolution. After this process shown in Figure 31 is complete, the 3D imagery is now available as a background for EWD scenes.

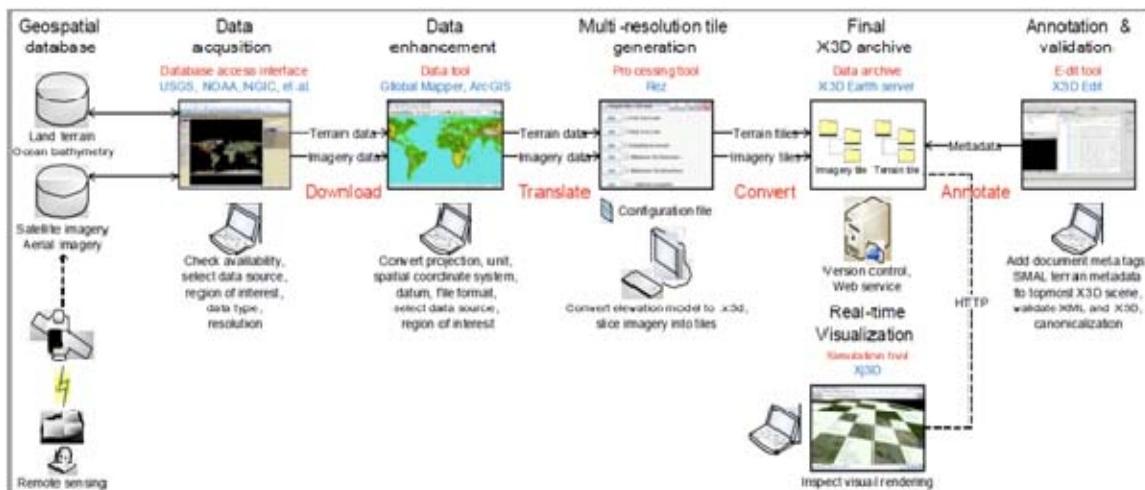


Figure 31. The Terrain-tile Production Chain from Global Mapper to Rez to Model Archive to X3D-Edit for Final Scene Creation (From Yoo & Brutzman, 2009)

3. Full Globe Coverage for X3D Earth

Since source imagery is so critical to multiple geospatial visualization projects, including EWD modernization, numerous student thesis opportunities have emerged at NPS to address the need. Currently, LT Dale Tourtelotte is beginning his thesis work to develop an open-source, royalty-free method for a full coverage 3D globe using the X3D International Standard. Using multiple imagery formats including Digital Nautical Charts (DNC), Digital Terrain Elevation Data (DTED), and National Geospatial-Intelligence Agency (NGA) satellite imagery, this research seeks to show the interoperability and “mash-up” capability of X3D Earth through processing and storing digital terrain data using the new Hamming Supercomputer located at NPS. Ultimately, an X3D Earth model resource repository will be created making high quality satellite imagery for web based training applications available to any Marine or Sailor.

D. X3D MODELS FROM ARMY MODEL EXCHANGE (AMEX)

The U.S. Army Program Executive Office for Simulation, Training and Instrumentation (PEO STRI) Targets Management Office and the Research, Development and Engineering Command (RDECOM) Virtual Targets Center sponsors the Army Model Exchange (AMEX). AMEX “was created to promote model reuse for all DoD agencies involved in modeling and simulation (M&S)” (AMEX, 2009). Since an initial repository of models is required for this work, AMEX was investigated and proved to be an excellent source for vehicle visualization for use with X3D Earth. The AMEX models complement the already-existing Savage and Savage Defense libraries. This section investigates the repository and the condition of its models upon download. In addition, it covers collaboration with the AMEX staff and the recommended meta data additions to promote re-use and sharing of these models for work on the EWD.

1. The AMEX Repository

The AMEX repository contains approximately 400 models ranging from U.S. and foreign aircraft to insurgent vehicles (AMEX, 2009). Many complex training scenarios applicable to today’s constantly changing battlefield can be populated with AMEX models. For this work, the first step after model download was to check the condition of

the X3D models upon download directly from the website at <https://modelexchange.army.mil> by viewing them in an X3D web browser. There are many browser options with the most popular being Xj3D, Octaga, BS Contact, FreeWRL and Instant Reality. All are available for download via the X3D Resources website at <http://www.web3d.org/x3d/content/examples/X3dResources.html>.

The results from the initial look at the models in each browser confirmed the high expectations for the AMEX models. They were viewable in three of the five browsers: Octaga, BSContact, and Instant Reality. In those browsers, each model was realistic and meticulously detailed. An example of one of the AMEX models immediately following download is shown in Figure 32.

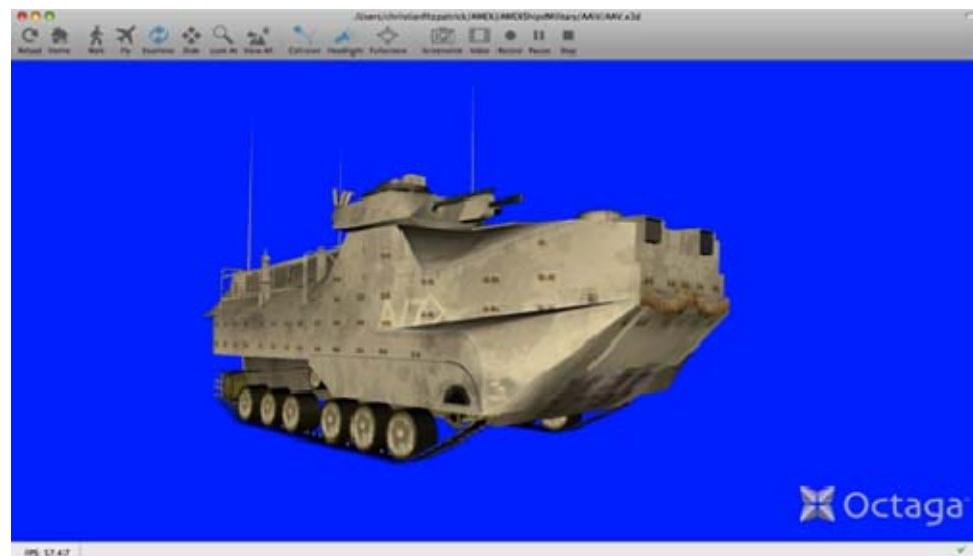


Figure 32. An Example AMEX Model of an AAV Viewed Immediately Following Download

2. Viewing AMEX Models in Xj3D and FreeWRL Browsers

Upon download, the AMEX models were not viewable in either the Xj3D and FreeWRL browsers. One major concern driving this investigation was that X3D Earth is viewable only in Xj3D and FreeWRL. Since Xj3D is the browser required for the EWD's 3D visualizations, it is imperative to troubleshoot the models to make them viewable in that browser. The first step was to check the Xj3D console output for each model when attempting to view it after download.

Each model seemed to have the same cryptic Xj3D warning and error message. The first was “image loaders not available” and the second was “could not find the definition file for the profile full.” The second error was caused by the specification for X3D profile. In all of the models, this was set to “Full.” To correct, the profile was modified to “Immersive.”

After this modification on all models, a second error surfaced related to the float value for the material node. X3D requires values between 0 and 1. In one example model, the material shininess value was 40, based on an incorrect range between 0 and 255. Thus, the value needed to be modified to a value between 0 and 1. Making this simple change allowed the model to be viewable in Xj3D. These two steps formed the process to modify and check all models downloaded from AMEX. X3D-Edit 3.2 was used to make similar edits to all of the selected models. Additionally, feedback was provided to the BRL-CAD team. A summary of necessary and recommended exporter changes is provided in Table 2.

Table 2. Required Modifications Made on AMEX Models to Enable Viewing in Xj3D

	Downloaded AMEX Model	Changes Made to Update
xml encoding	ISO-8859-1	UTF-8
DOCTYPE X3D PUBLIC	ISO//Web3D//DTD X3D 3.0//EN	ISO//Web3D//DTD X3D 3.2//EN
DOCTYPE X3D PUBLIC	http://www.web3d.org/specifications/x3d-3.0.dtd	http://www.web3d.org/specifications/x3d-3.2.dtd
X3D Profile	Full	Immersive
X3D version	No input	3.2
X3D xsd::noNamespaceSchemaLocation	http://www.web3d.org/specifications/x3d-3.0.xsd	http://www.web3d.org/specifications/x3d-3.2.xsd
Material Node shininess value	0-255	0-1

3. Scenario Authoring and Visualization for Advanced Graphical Environments and Savage Defense X3D Model Archive

After modification, the models will be placed into the Scenario Authoring and Visualization for Advanced Graphical Environments and Savage Defense X3D Model Archive maintained by the MOVES Institute at NPS. To coordinate this second level of storage, multiple email exchanges and teleconferences were coordinated with AMEX staff to discuss collaboration. After discussion, the agreement for AMEX models

downloaded and placed into the Savage Defense Archive was to designate them “For Official Use Only” (FOUO). FOUO means official use for U.S. government personnel and contractors. This made the models available for U.S. student class projects, thesis work and 3D training applications. Thus, usage of models is specific to NPS research endeavors and their applications to U.S. forces. In order to ensure compliance, the FOUO requirement is clearly stated in the metadata of each model downloaded from the repository, as shown in Figure 33. Additional metadata was added to track modification and to accurately describe each model.

```

<meta content='UH1NHuey.x3d' name='title' />
<meta content='A USMC Utility Helicopter created and maintained by the AMEX' name='description' />
<meta content='Army Model Exchange (AMEX)' name='creator' />
<meta content='9 January 2009' name='translated' />
<meta content='25 Aug 2009' name='modified' />
<meta content='Christian Fitzpatrick' name='translator' />
<meta content='https://modelexchange.army.mil' name='reference' />
<meta content='USMC Huey Army Model Exchange (AMEX) X3D model' name='subject' />
<meta content='For Official Use Only (FOUO)' name='accessRights' />
<meta content='X3D-Edit, https://savage.nps.edu/X3D-Edit' name='generator' />
<meta content='.../license.html' name='license' />
<meta content='https://SavageDefense.nps.navy.mil/SavageDefense/AircraftHelicopters' name='identifier' />
```

Figure 33. FOUO Requirement Specified in Added Meta Data

4. Savage Modeling and Analysis Language (SMAL)

The need for tactical metadata to ensure appropriate usage in EWD scenes is also critical. Future work includes improving the user interface within X3D-Edit 3.2 to make the addition of tactical metadata (or SMAL) easier. SMAL is tactical data added to each model specifically related to its capabilities and limitations to ensure proper use in virtual environments (SMAL, 2009). Adding this data enhances the effectiveness of the repository by embedding performance data later accessed to run an autogenerated X3D scene. This data falls into three categories: inherent, parametric, and instantaneous. Inherent metadata “includes the physical size and weight of the object” (Rauch, 2006). Other examples of inherent metadata are speed, acceleration, and detection or engagement range (Rausch, 2006). Parametric data are “environmental conditions, associations between entities, terrain and objects in the terrain” (Rausch, 2006). Finally, instantaneous data “consists of items required to describe the situation at a given moment in time. A description of the scene at the first moment of a tactical scenario is both an

instantaneous description of the scene and a large part of the initialization parameters” (Rausch, 2006). Examples of instantaneous data are position and orientation, current speed, acceleration, fuel state, and time.

E. X3D-EDIT MODELING TOOL

The X3D-Edit 3.2 modeling tool shown in Figure 34 is available for download via the X3D Resources website and is utilized by NPS students in the beginning and advanced X3D courses. It is intuitive and has many helpful troubleshooting capabilities. X3D-Edit was used to make changes to the downloaded AMEX models for this work. Regular expressions for search and replace customization were considered to change the X3D files, but to ensure accuracy the files were modified one-by-one. The Savage team specifically chose 111 models applicable to Marine Expeditionary Unit (MEU) missions for download. All models were modified as specified in Table 2 and the appropriate metadata was added to assist with the future creation of a database that Navy and Marine Corps personnel can use to create their own training scenes, with the end state being that these scenes may be replayed and viewed by large units training in the EWD.

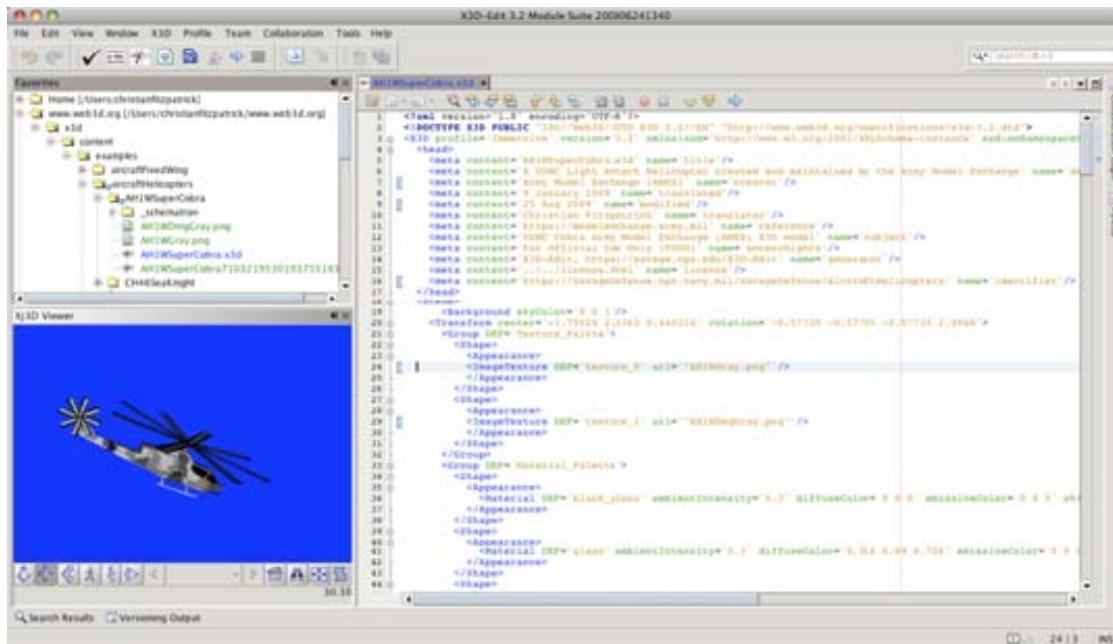


Figure 34. X3D-Edit 3.2 Screen Layout shown with Cobra model.

The X3D-Edit 3.2 capability used for validation is the Quality Assurance (QA) drop-down menu shown in Figure 35 (Canonical XML, 2001). The collected validation methods are much more thorough than the browser console windows because they meticulously go through each file to find errors in format and syntax. Errors are sequentially presented with links in the output window, making the changes quick and painless. The following tests are performed during the X3D Edit Quality Assurance (QA) tests: (X3D Resources, 2009)

- XML well-formed
- XML Validation using X3D DTD (Doctype)
- XML Validation using X3D Schema
- X3D to ClassicVRML.xslt stylesheet conversion error checks
- X3D Schematron rule-based consistency checks

This is a tremendously powerful capability for all X3D scene authors to ensure quality and accuracy of work.

Once all format and syntax errors are corrected, each of the model files can then be canonicalized, finalizing the modifications. Canonicalization (C14N) eliminates file ambiguities such as extra whitespace, which might negatively impact file security, compression or parsing performance (Canonical XML, 2001). C14N normalization ensures that any differences in subsequent version-control updates are specifically limited to substantive changes (Canonical XML, 2001).

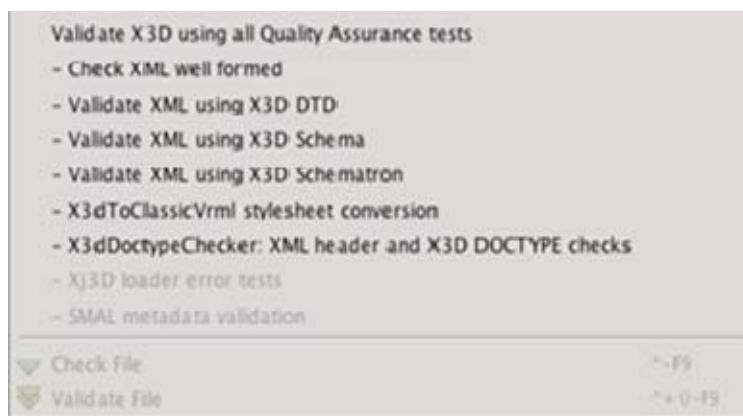


Figure 35. X3D-Edit Quality Assurance Launch Button and Component Tests in Drop-down Menu

F. MODIFICATIONS TO AMEX MODELS

1. Material Node Modifications to AMEX Models

For the modification of the material node for the textures in each of the models, the data range for the shininess in each model was reviewed. X3D specification requires inputs to be between 0 and 1 (X3D Specification, 2003). The models downloaded from AMEX all have values between 0 and 255 indicating an authoring error. This finding was reported to AMEX.

With the initial values for shininess between 0 and 255, the data was scaled between 0 and 1. The focus was to get all models viewable in Xj3D to allow the most compelling usage of the models in X3D Earth scenes. Thus, a simple calculation for scaling the shininess input was used. In order to make the data range between 0 and 1, the values were scaled to a percentage between 0 and 255. For example, if a model has a shininess input of 128, the shininess value was changed to 0.5. Once this change was made, the models were easily viewable in Xj3D, and more importantly, easily visible when inlined into an X3D scene that includes X3D Earth and other models.

2. Browser Performance after Modifications

After modifications across all the selected models were complete, the next task was to confirm that the modifications enabled viewing in Xj3D. Performance in Instant Reality and Octaga was also reconfirmed, but now with the modified material nodes. As expected, all models were now viewable in the Xj3D browser with an example shown in Figure 36. Also, the models were still viewable in Octaga, Instant Reality and Bit Management's BS Contact browser. Multiple screen shots were compared to ensure the models were not degraded in any way. The next focus was to improve documentation on each model to ensure compliance with repository rules and realistic emplacement within scenes.

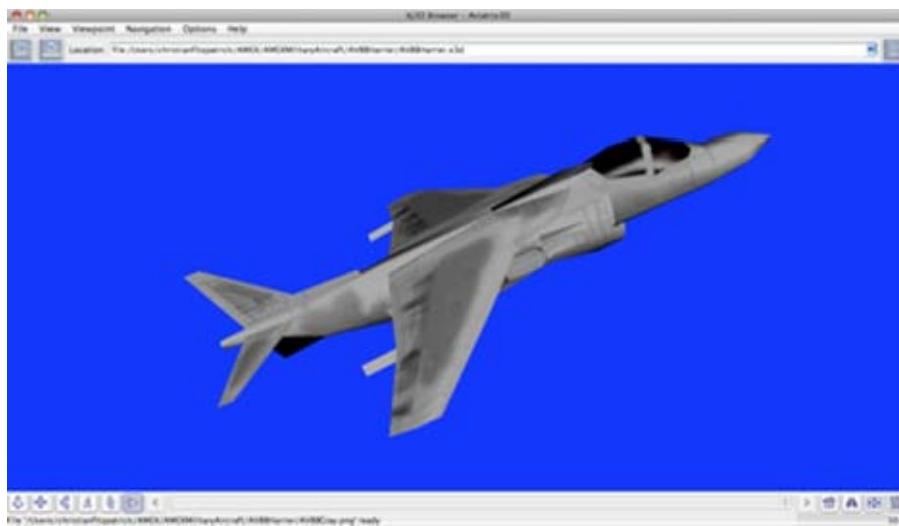


Figure 36. Modified AMEX Model of an AV-8B Harrier Working in Xj3D Browser

3. Additional Modifications to AMEX Models

To improve documentation, relevant metadata was added at the beginning of each file. The metadata included a description of the model, date of modification, web link in model archive, etc. The most significant addition was the subject metadata, which allowed numerous users to access the models based on the search criteria placed in a common search engines such as Google, Bing or Yahoo. This is where the tactical metadata (SMAL) discussed earlier may be added as well. The performance metadata enables numerous future applications (Rauch, 2006). Emplacing real-world restrictions on the models helped to guarantee realism for future training applications.

The next modification was to ensure that each of the files followed the XML structure and format for X3D. In the majority of the downloaded models, the DEF names used for the material and appearance nodes did not follow proper XML format. The majority of the names used in the original downloaded files had whitespace within the name. For example, a “white semi” or “black gloss” DEF name was changed to *whiteSemi* and *blackGloss* respectively in order to comply with XML standards, which forbid embedded whitespace in identifier names (X3D Specification, 2003). Standardized coding techniques ensure complete understanding and flexibility between units.

The final modification made was to animate the models, if possible. For example, the main rotors on select helicopter models can be continually rotated with the addition of the <OrientationInterpolator> (Brutzman & Daly, 2007). For example, the small portion of code in Figure 37 was added to the AH-1W Cobra model to rotate the main rotor 360 degrees (0 to 2π radians) about the y-axis (represented as 0 1 0). Its implementation made the model more realistic and interesting to view.

```
<OrientationInterpolator DEF='spinRotors'
    key='0.00 0.25 0.50 0.75 1.00'
    keyValue='0 0 1 0 0 0 1 1.5708 0 0 1 3.14159 0 0 1 4.7123889 0 0 1 6.2831852' />
```

**Figure 37. <Orientation Interpolator> Used in the AH-1W Cobra Model
Downloaded from AMEX**

G. ANIMATING SCENES

Creating animated scenes by combining enhanced 3D imagery and moving high-fidelity 3D models was the ultimate goal of this modeling work. In order to create the scenes, a template X3D file was developed to inline various imagery and models specific to training objectives. During the Rez processing describe earlier, an image tree with five levels of detail (LOD) was created (Thorn, 2007). The zero LOD folder contains the X3D file used for inline within the template. This specific file references all the other “sliced” images within the LOD tree, allowing the viewer to zoom in or change viewing perspective within scenes.

The AMEX models were added to scenes using the <Inline> node. Since Global Mapper creates a geo-referenced image, an X3D author is able to position the model into the scene using the actual latitude and longitude values, as well as altitude above sea level in meters. Latitudes and longitudes were entered in decimal format. The model’s <GeoPositionInterpolator> node was used to specify the orientation about the x-, y-, or z-axis (Brutzman & Daly, 2007). Shown in Figure 38, movement of the models can be easily modified using the <GeoPositionInterpolator> by adding keys that equate to x, y, and z positions on the imagery (Brutzman & Daly, 2007). The x position would be equivalent to the latitude, the y to the longitude, and the z to the elevation in meters.

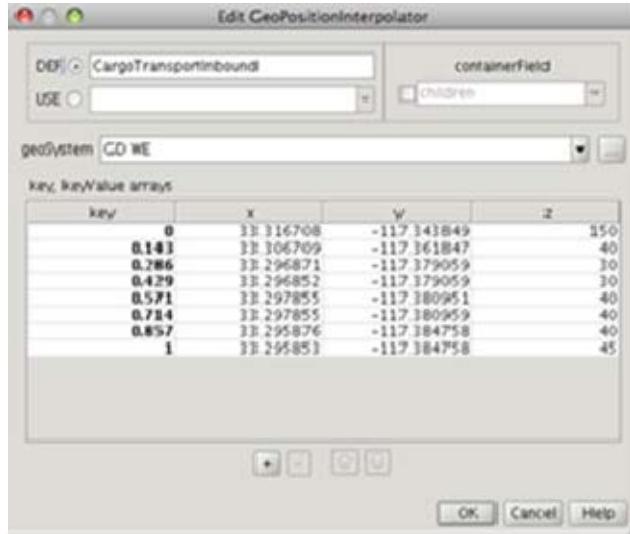


Figure 38. <GeoPositionInterpolator> Editor for Latitude, Longitude and Elevation Input for Animation

In order to enhance realism, the orientation of each model was also changed as the model moves from point to point or, in this case, from key to key within a scene. The <OrientationInterpolator> uses the same keys to change orientation about the x-, y-, or z-axes by a specific angle, which is the last input into this node. In order to make the animations event-driven, the usage of a <TouchSensor> was included to create an animation trigger, enabling models to move based on a controller's input. This is useful when animating time or event-driven missions such as pre-planned fires from naval gunfire and aircraft. Examples of each of these nodes can be seen in Appendix C.

1. MCB Camp Pendleton Scenario Development

The scenario developed as a proof of concept for EWD animations was based on the activities of a notional insurgent organization operating from the actual K-2 (Kilo Two) MOUT facility on MCB Camp Pendleton. The scenario begins with a Cessna transport aircraft arriving at a nearby airfield. Immediately upon landing, the aircraft taxis over to a cargo offload area and drops some large boxes from a side cargo door. In the vicinity of the cargo offload area on the airfield, a Nissan truck is waiting and watching the aircraft shown in Figure 39. Upon the departure of the aircraft, insurgents are seen leaving the vehicle to gather the boxes dropped from the aircraft. Once the insurgents

return to the vehicle, the vehicle departs on a roadway parallel to the airfield. The vehicle proceeds east and then makes a turn to the north on a roadway leading directly to the K-2 MOUT facility.

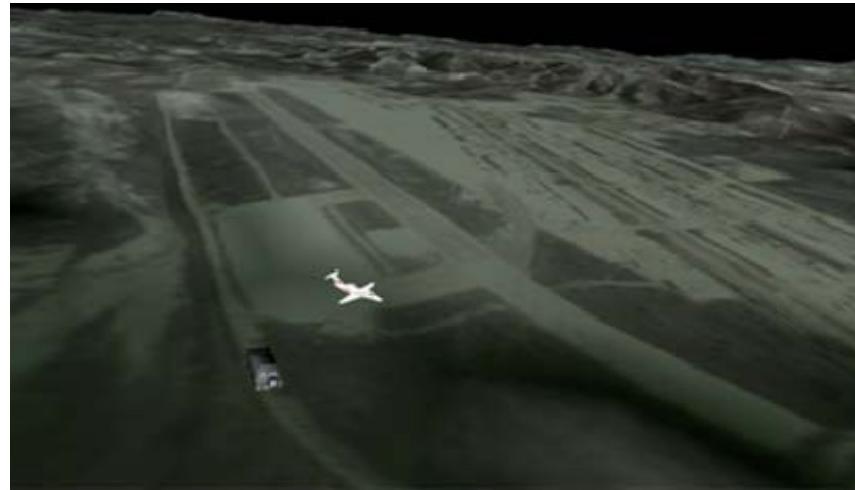


Figure 39. Snapshot of Animation for Suspected Weapons Drop at MCB Camp Pendleton shown in Xj3D Browser

This scenario is similar to one given to a MEU for a Motor, Mechanized, or Helicopter Raid. In addition, this might be a mission where direct action could be assigned. The MEU Commander has a number of options, and the enhanced visualization of the terrain and enemy movements would help prepare his staff to formulate the most effective plan to engage the enemy. The EWD with real-world animations can potentially improve staff interaction in the early stages of R2P2 training during the predeployment work-up cycle.

The most critical aspect of the animations in X3D is linking the `<GeoPositionInterpolator>` and `<OrientationInterpolator>` with the `<GeoLocation>` and `<Transform>` nodes for the AMEX model used in the scenes. Linking events between these nodes is accomplished through `<ROUTE>` statements, which can be seen in Appendix C.1 in which the `<GeoLocation>` node is changed by the values specified in the `<GeoPositionInterpolator>` node (Brutzman & Daly, 2007). The values in the `<GeoPositionInterpolator>` are a list of latitude and longitude values that specify a route. In the case of the code shown in Figure 40, the route described is the Cessna's flight path

into the airfield. This same concept was used to animate the vehicle's departure from the airfield and movement to K-2. All events passed between nodes via <ROUTE> must pass strong type checking to ensure that only correctly formed values are used.

```
<GeoPositionInterpolator DEF='CargoTransportInbound'
    key='0 0.143 0.286 0.429 0.571 0.714 0.857 1'
    keyValue='33.316708 -117.343849 150
              33.306709 -117.361847 40
              33.296871 -117.379059 30
              33.296852 -117.379059 30
              33.297855 -117.380951 40
              33.297855 -117.380959 40
              33.295876 -117.384758 40
              33.295853 -117.384758 45' />
```

Figure 40. <GeoPositionInterpolator> Using Latitude, Longitude and Elevation to Position an Aircraft within a Scene

2. Further Ideas for Integration with MEU Training

Another possibility for enhancing realism is to attach a moving viewpoint to an aircraft or vehicle within a scene. The proof of concept chosen for this animation is a viewpoint added to a UAV. In order to show the concept, the viewpoint is placed slightly above and offset from the UAV, so that the viewpoint shows the collection of real-time data over imagery. A Global Hawk UAV is in a circular pattern above NAB Coronado in San Diego shown in Figure 41. The east-west pattern observes all roads and entry points to the base. Overall, the concept can be applied to any scenario with the addition of a single line of code.



Figure 41. Snapshot of Animation Using Viewpoint Node Added above Global Hawk UAV Simulating Intelligence Collection

3. Application of Agent-based Simulation

Scripted animations are effective when attempting to meet specific training and readiness goals; however, they can be somewhat predictable. To further expand EWD training capabilities, building tactical agents using SimKit or Viskit to establish behavior libraries is recommended for future work. A repository of numerous enemy behaviors enables verification of tactics, techniques and procedures (TTP) crucial to the development of new amphibious doctrine. This also addresses the CMC's directive to review amphibious policy and doctrine.

H. CONCLUSIONS

Animated scenes using the systems like X3D Earth is a critical enhancement to the EWD. These scenes can create an intelligence picture of enemy activities occurring within a specified area of operation. In addition, X3D Earth offers considerable flexibility for staff instructors using the EWD for training since they will be able to train in any region throughout the world. The Expeditionary Strike Group and Marine Expeditionary Unit staffs now have the ability to pre-plan operations using enhanced 3D terrain visualizations. Another interesting aspect of this process is the planned "developers." In modernizing the EWD, introducing X3D modeling tools to young Sailors and Marines from operational units is recommended, enabling them to create applicable, real-world training animations for their unit's training. Their animations will be viewable on a large-scale at the EWD or on a smaller scale within an open-source 3D browser available online. The comprehensive process developed from scene ideation to final animation provides graphics training to entry-level Sailors and Marines and enhances battle space visualization for more experienced mission planners.

I. SUMMARY

This chapter covered the integration of Army Model Exchange models with X3D Earth terrain into X3D scenes. The AMEX models required some modification for integration into the scenes and that process was explained. In addition, the chapter showed how models within the scenes are animated. This is a powerful capability recommended for integration into the modernized EWD.

V. APPLICATIONS OF DIGITAL HOLOGRAPHY TO THE EWD

A. INTRODUCTION

The third phase of this work identifies additional technologies that may potentially expand the training audience of the EWD. Addressing the movement of the ship models and the fixed terrain display only modernizes the EWD in its current configuration as a staff trainer. A practical extension of this large-group capability focuses on small unit training, specifically Marine infantry squads. This chapter explores the usage of static holography to train infantry squads on ground tactics upon reaching the objective following an amphibious landing. It identifies the data required to produce a static hologram for training and then briefly describes the production process. The results of two user studies using holography are also presented showing the potential benefits for tactical visualization. Finally, methods to integrate holography into the EWD are recommended.

B. A BRIEF HISTORY OF HOLOGRAPHY

Dennis Gabor, a German electrical engineer, discovered holography in the late 1940s (Fuhrmann et al., 2009). While in the lab working with an electron microscope, Gabor was struggling with the lens distortion of spherical electron waves. To correct the distortion, he proposed recording the wave shape in the electron microscope and then correcting the distortions using two optical beams (Benton & Bove, 2008). Although skeptics were first critical of his work, his colleagues were astonished when they observed his results. Through interference, Gabor was able to correct the shape of the waves. Ultimately, this work earned him the Nobel Prize for Physics in 1971 (Benton & Bove, 2008).

Following Gabor in 1962, two electrical engineers, Emmett Lieth and Juris Upatnieks, from the University of Michigan at Ann Arbor worked on a secret, side-looking radar to track flight paths. Influenced by Gabor's 1947 paper, they recreated his work using the newly invented laser and their "off axis" technique, allowing for the separation of image components (Benton & Bove, 2008). Their method worked and

further confirmed Gabor's efforts 10 years earlier, but more compelling were the detailed images created with their technique. Quickly, they began to expand their work by recording three-dimensional tabletop scenes. Leith and Upatnieks showcased their work at the fall meeting of the Optical Society of America in 1964. They called their work "wavefront reconstruction photography" (Benton & Bove, 2008). This was considered the birth of holographic imaging as is known today.

C. DATA REQUIRED TO PRODUCE A HOLOGRAM FOR THE EWD

To integrate with this work, static holography can be used to show the target objective area following an amphibious landing. First, physical ship models and X3D animated scenes might separately depict movement from amphibious shipping to the target objective in large dynamic displays. Then, static holography is used to visualize the objective in a sand table setup to train infantry squads. However, moving images cannot be superimposed on the holography.

To augment the example animations of notional enemy activity on MCB Camp Pendleton shown in the Chapter IV, the K-2 MOUT training range was selected as the objective. K-2 is located northeast of the airfield on Camp Pendleton. During predeployment training, the 11th, 13th and 15th MEUs use the landing beach at Camp Pendleton and the Special Operations Training Group develops tactical scenarios using the training ranges within the base. The scenario used in this research is considered realistic and applicable for amphibious training.

The model used for K-2 was developed by L-3 Communications for the BASE-IT project. The data set was originally developed in Autodesk's 3ds Max using Light Detection and Ranging (LIDAR) data for the ground surface. The buildings were emplaced on the surface using simple polygons. Since 3ds Max software was not available for this work, a conversion script was used to convert the original object file from 3ds Max to a Maya file. Maya 2008 software was then used to make modifications and corrections to the model since multiple polygons and all image textures were lost after conversion. In order to ready the model for hologram production, all textures were

replaced on building surfaces within the K-2 model. In addition, some surfaces were also missing, and Maya 2008 was used to manually re-draw new surfaces to complete the model. An image of the completed model is shown in Figure 42.



Figure 42. 3D Model of K-2 Produced shown in Maya 2008

Once complete, the digital 3D model was forwarded to Zebra Imaging for hologram production and printing. Their programming and graphics staff reviewed the model and produced an example movie file of how the hologram might look upon completion. Since both user studies to be discussed later in this chapter point out concerns as to the length of time to develop a hologram and put into the hands of users, the length of time to complete the model processing was noted. For this specific model, one week was required to modify and ready for hologram production. Once the model was processed by Zebra Imaging, they forwarded a preview of the how the final hologram might appear once printed (Figure 43), which required another day.



**Figure 43. Preview of Kilo-2 Hologram Prior to Printing
(From Zebra Imaging, Inc.)**

D. CONSTRUCTION OF THE STATIC HOLOGRAM

To create this hologram of the Kilo 2 MOUT facility, Zebra Imaging uses proprietary software to position a virtual camera directly overhead the facility model described in the previous section. The model is rasterized from the virtual camera's viewpoint to create a set of *hogels*, which are holographic elements. The hogels contain all information about each specific point in a model including its location, elevation and texture. They are similar to pixels in 2D images. A single hogel when lit at a 45-degree angle produces a projection of the entire model. When constructing the K-2 hologram, multiple hogels were placed side-by-side onto a 2 foot by 2.5 foot sheet (Benton & Bove, 2008). There were a total of 480,000 hogels used in the K-2 hologram (600 x 800). Each hogel placed on a hologram is exactly the same and they need to be meticulously positioned in structured rows and columns prior to use.

The most important aspect in viewing the hologram correctly is the proper lighting of the hologram in both position and intensity. Limitations on viewing angles are also important. Just as in 2D images, when pixels are lit from a light source, color is reflected and the image is viewable. The same concept applies to holograms and, more specifically, to hogels. Hogels require a direct light source orthogonal to the actual hologram and the viewer must view the hologram from the vicinity of a 45-degree angle (Smith, 2007). A single hogel created from a 1280 by 1024 image produces over 1.3 million projections. As light reflects off the hogels, the human eye is able to detect one projection from each of the 480,000 hogels. Each projection from a specific hogel comes together to produce the entire model that was rasterized previously. With the enormous amount of data produced by the hogels, holograms allow viewing from multiple perspectives in the three dimensions.

E. PREVIOUS STUDIES OF STATIC HOLOGRAPHY FOR TRAINING

There are a limited number of user studies available on the use of holography for training; however, the two studies reviewed in this work show the potential benefits of using this visualization tool. The first training task reviewed was a Joint Terminal Air Controller's (JTAC) control of aircraft to deliver ordinance on target near friendly troops.

JTACs perform the same mission as Forward Air Controllers (FACs) in the Marine Corps. In a Marine Expeditionary Unit (MEU), there is one Air Officer and two FACs assigned to the Infantry Battalion. The availability of up-to-date holography may benefit their training with the MEU's aviation assets. The second training task reviewed was path planning for tactical scenarios. In that user study, Special Weapons and Tactics (SWAT) Teams used static holography for planning routes to find targets in an unfamiliar environment. This study has obvious applications to Marine Infantry Squad tactics in an urban environment. The results from both studies are discussed below.

1. User Study Conducted by the Air Force Research Lab (AFRL)

In mid-2007, the Air Force Research Laboratory (AFRL) and Zebra Imaging, Inc., began a study with the Joint Improvised Explosive Device Defeat Organization (JIEDDO) to determine if digital holography might assist with detection of improvised explosive devices (IEDs) on the battlefield (Martin et al., 2008). The study ended quickly since the imagery resolution required to perceive disturbed earth that might be concealing an IED was not available to produce the holograms. However, from the initial demonstrations of holograms, a number of pilots and qualified JTACs agreed that holographic imaging might assist in terminal air control training to develop a cognitive map of the operations area (Martin et al., 2008). With this change, AFRL began to assess the JTAC and FAC planning process and conducted a user study with the holograms.

During their study, nine JTACs were given the opportunity to rate and compare the effectiveness of 2D photographs versus 3D holograms during planning. They rated various measures of effectiveness on a scale of 1 to 10 (poorest to best). Overwhelmingly, “the results of the evaluation indicate that the 3D holograms are an effective tool for JTAC mission planning and execution” (Martin et al., 2008, p. 33). 3D holograms seemed most effective in reporting the collateral damage estimate (CDE), determining the height of buildings and other structures, maintaining lines of fire and sight, and determining JTAC overwatch positions (Martin et al., 2008).

Most JTACs also appreciated the new ability to determine the difference between rooftops and courtyards provided by the holograms. Although this seems trivial, 2D

imagery often makes such distinctions hard to discern. Overall, Figure 44 shows the average mission effectiveness scores comparing 2D imagery to 3D holography.

There were some limitations noted during the study. For example, the holograms used in this exercise required sunlight for optimal viewing. However, varieties of synthetic light sources were used at a 45-degree angle for indoor and outdoor exercises and performed well (Martin et al., 2008). Most JTACs commented that using holograms during a mission might still be feasible during night operations. Overall, the outstanding performance of the holograms within this user study prompted considering their use for possible inclusion within the target-area phase of this EWD work.

Mission Planning Tasks	Mean Rating 2D Photograph	Mean Rating 3D Hologram
ID Threats	5.8	7.2
Target Analysis	6.3	7.5
Friendly Disposition	6.7	7.4
Weapons Employment	5.9	7.9
Mission Planning Tasks (Mean)	6.1	7.5
Mission Execution Tasks		
Target talk-on	7.1	8.4
Collateral damage estimate	6.4	8.9
Battle damage assessment	6.6	8.0
Mission Execution Tasks (Mean)	6.7	8.4
Planning and Execution Subtasks		
Determine relative height of buildings	4.4	8.4
Determine relative height of other objects	3.6	7.9
Determine relationship to vehicles	5.4	7.2
Determine LZs	5.0	8.1
Determine Ingress/Egress Routes	6.8	7.8
Interpret Shadows	5.9	8.3
Interpret Vegetation	5.9	7.9
Determine line of sight	4.1	8.3
Determine line of fire	4.0	8.7
Determine breaks between buildings	5.6	8.3
Position teams, snipers,	4.8	8.6
Define cordons	6.3	7.8
Determine JTAC overwatch position	5.6	8.8
Planning / Execution Subtasks (Mean)	5.2	8.2

Figure 44. Results from AFRL and Zebra Imaging User Study (From Martin et al., 2008)

2. Path Finding for Special Weapons and Tactics (SWAT) Teams

Texas State University in San Marcos, Texas conducted another user study with local Special Weapons and Tactics (SWAT) teams (Fuhrman et al., 2009). This study was more “hands-on” than the AFRL study since actual SWAT team officers were given specific tasks to complete using holograms. Within a three-story laser tag facility in Austin, Texas, SWAT officers prepared to find hidden targets. The targets were chairs that were colored either red or yellow. The first red target was described as relatively easy to find, but the second yellow target required the navigation through multiple levels of the facility (Fuhrman et al., 2009). Eight participants in the study were given an introduction to the holograms since no one had previous experience using them. Once all officers felt comfortable using the holograms, the study began.

All eight subjects were asked to find the red and yellow target using both a 2D map of the facility and then a 3D hologram of the facility. Randomly, a single SWAT officer entered a room and was told the location of the target. Then, he was given either a hologram or 2D map for use in planning (Fuhrman et al., 2009). The study compared operator performance when using either holography or a map, by measuring wayfinding and target identification. The data collected was the time in seconds that it took the subject to find the target upon leaving the planning room. The entire user study was complete once all participants performed missions and found the two targets using each planning tool. This task of gaining geospatial intelligence is actually quite similar to typical SWAT team mission planning. This scenario is also somewhat similar to the planning that infantry Marines ordinarily participate in when preparing for operational missions.

The results from the study pointed to the effectiveness of the holograms. The first task, finding the red chair, did not show that planning with a 3D hologram was a significant advantage. However, for the more difficult task, searching for the yellow chair, there was an advantage to using the hologram as shown in Figure 45 (Fuhrman et al., 2009). This specifically shows the positive impact a true 3D representation has on building a common operational picture needed to perform a task (Fuhrman et al., 2009).

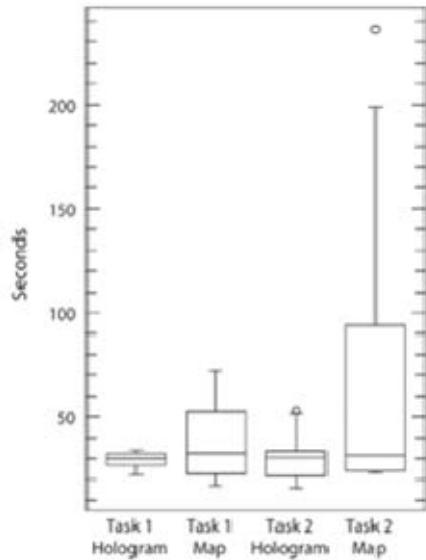


Figure 45. Box-and-whisker Plot of Wayfinding Performance for Both Geovisualizations Showing Better Target Finding Using Holography (From Fuhrman et al., 2009)

The box-and-whisker plot shows that all users were able to quickly complete the more difficult task using the hologram. With a 2D map, some users had difficulty and there were significant performance outliers. Overall, the response was positive from the participants. “Seven of the total of eight participants stated that holograms might be useful and effective tools in SWAT operations” (Fuhrman et al., 2009). Others said that holograms were an excellent reference for planning routes and obtaining survey knowledge. Some subjects worried about the cost of the technology and the timeframe required to produce a hologram (Fuhrman et al., 2009). These concerns deserve close consideration.

For the K-2 model used in this work, the LIDAR data was already provided and the majority of the 3D structures were in place. Much of the work was in replacing the textures one-by-one onto the buildings and then in making any necessary corrections for any missing geometry after conversion. Overall, this process to convert took approximately 1 week of work in Maya. Once complete, the model was forwarded to Zebra Imaging. Within hours, a movie file visualizing the hologram was returned and

upon approval, the hologram was printed. The process took approximately eight days to fully complete at an approximate cost of \$2300.

F. LIMITATIONS OF HOLOGRAPHY IN EWD

Although holography has performed well in multiple user studies as shown in the previous sections, the EWD's unique setup presents some challenges for its proper implementation. First, viewing holographic images from the side bleachers will be problematic due to the shallow viewing angle. The next section presents a small group viewing solution alleviating this issue. Second, the modernized EWD is based on open source, open standard technologies. Use of holography requires continuous funding to maintain current visualizations required for the most realistic tactical training. Considering both of these limitations, the use of holography is still recommended since it offers a “true” 3D representation of terrain data for tactical training and mission planning.

G. APPLICATIONS TO EWD

Digital holography can be used as one supporting component in the process of upgrading the EWD if the configuration of the facility is changed. It is best viewed with a light source orthogonal to the actual hologram. For its integration into the EWD, this thesis recommends reducing the size of the current EWD display area to make room for 3-4 planning tables that show holography. These additions to the large-area EWD display can enable Marines and Sailors to closely discuss the objective area layout and surrounding terrain and building implications to the mission. Note that planning table needs to have a light positioned correctly to ensure proper display of the hologram as well. Figure 46 shows a concept of the small holography planning table that can be used to train Marine Infantry Squads at the modernized EWD.

Close-up viewing of key locations by individuals in small teams can provide necessary support for hands-on training, and actual mission rehearsal. First-hand examination of the holographic imaging can also provide intelligence officers another tool they might use in order to build a common operational picture for their commanders. They may also receive training at the EWD on how to direct the creation of data to

produce a high-fidelity hologram. Figure 46 shows a concept of the small holography planning table that can be used to train Marine Infantry Squads at the modernized EWD.



Figure 46. Virtual image of Infantry Squad Discussing Tactics Using a 3D Hologram (From Zebra Imaging, 2009)

H. CONCLUSIONS

Static holography has proven effective in some small-scale user studies over the past two years, and it has also been used on the ground in Iraq and Afghanistan with similar positive results. With more exposure across different user groups, holography can soon augment and even replace 2D imagery for geospatial intelligence gathering. Since data can be simply created in numerous modeling tools including Maya, X3D and Google SketchUp, custom holograms can be produced more quickly than ever. A hologram's depth cues along with the spatial mapping combine the best aspects of web-based 3D and 2D maps for planning. Nevertheless, limitations on lighting and viewing angles restrict the usage of holograms to small tables for small groups.

I. SUMMARY

This chapter describes the third phase of this work, which identifies static holography as an additional technology available to expand the EWD training audience to

small units. This chapter covers how static holography can be used to train infantry squads on ground tactics upon reaching the objective following an amphibious landing. It also shows the data required to produce a static hologram for training and then briefly describes the production process. The results of two user studies using holography are presented and analyzed as a basis for this technology to be recommended for the EWD modernization project.

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VI. ACQUISITION CONSIDERATIONS FOR EWD MODERNIZATION

A. INTRODUCTION

This chapter provides a general overview of the acquisition process in the Marine Corps and identifies the organizations supporting this work through the Joint Capabilities Integration and Development System (JCIDS). The overview provides a clear understanding of where this thesis work fits into JCIDS. In addition, it reviews specific MEU training objectives that can potentially be met by using an improved EWD. Understanding this process, while focusing on the users' training needs, is necessary for EWD modernization to become a properly supported and effective program effort.

B. ACQUISITION PROCESS IN THE USMC

1. Joint Capabilities Integration and Development System (JCIDS)

In June 2003, the Chairman of the Joint Chiefs of Staff (CJCS) approved the JCIDS process through the release of the CJCS Instruction 3710.01C (Cook, 2006). This framework was created to foster joint collaboration between the armed services on future warfighting capabilities. "JCIDS increases the power of the Joint Staff and the JROC to decide which new weapons and technology capabilities will reach the hands of Soldiers, Sailors, Airmen and Marines" (Cook, 2006, p. 3). It also ensures programs are joint from their inception. Considering the open source, open standard requirement placed on the technologies recommended through this research, the modernized EWD has the potential to become a joint training facility offering visualization solutions for any capability identified through the JCIDS process.

2. Capabilities Based Assessment (CBA)

Guided by JCIDS, the Marine Corps' Training and Education Command (TECOM) begins the process to obtain or upgrade a training system such as the EWD by conducting Capabilities Based Assessment (CBA). This process analyzes the requirements necessary to meet a specific capability. The first step in the CBA is the

Functional Area Analysis (FAA), which identifies operational tasks, conditions and standards needed to accomplish military objectives (Cook, 2006). In order to get the best data for the FAA, TECOM works closely with operational forces to collect feedback. For example, the Marine Corps Center for Lessons Learned (MCCLL) within TECOM is a major source for feedback and contributes across numerous capability assessments. Quantitative data on specific capabilities can be obtained from the Operations Analysis Division (OAD) within the Marine Corps Combat Development Command (MCCDC). Once requirements to meet a specific capability are defined in a formal FAA document, a Functional Needs Analysis (FNA) then produces a list of shortfalls that exist across all services (Cook, 2006). Once that list has been generated, solutions to fill training gaps are then considered through the Functional Solutions Analysis (FSA) (Cook, 2006).

The FSA is the third step of the CBA, as shown in Figure 47. TECOM and Program Manager, Training Systems (PMTRASYS) collaborate in this step to make an “assessment of potential DOTMLPF and policy approaches to solving (or mitigating) one or more of the capability gaps identified in the FNA” (ACC, 2009). DOTMLPF is an acronym for doctrine, organization, training, material, leadership, personnel, and facilities used as a guide when considering new training capabilities (Under Secretary of Defense, 2008). It ensures that all possible solutions to training gaps are considered. In some cases, a material solution may not be needed. There may be a pre-existing system that can support the training objective, so that acquisition of a new system is not required. For example, the EWD is a pre-existing demonstration tool with training applications that can meet capabilities identified in the FAA. Once TECOM and PMTRASYS compile the FSA, there is one final review prior to releasing the Initial Capabilities Document (ICD).

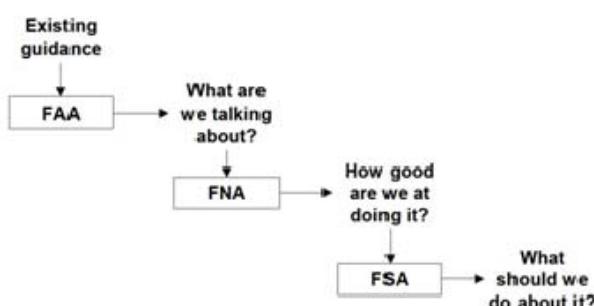


Figure 47. Simplified diagram of CBA Inputs (From JCS-8, 2006)

The Post-Independent Analysis (PIA) serves as the last review of the FSA. This allows the TECOM one final opportunity review the recommendations from the FSA. The PIA is conducted by a team not involved with the FSA and ensures that all possible solutions are considered. Although the DOTMLPF guides the FSA across a number of solutions, there still may be an additional option that has not yet been considered. Once the PIA is complete, TECOM then drafts the Initial Capabilities Document (ICD), which is the first key document required in the JCIDS process.

3. Material Solution Analysis Phase

A Material Development Decision (MDD) is made when the ICD outlines a material solution to bridge the gap identified in the FNA. This decision begins further analysis, which ultimately becomes part of the Capabilities Development Document (CDD). The CDD comprises “the analysis of alternatives, associated integrated architectures, capability roadmaps, concept refinement and technology development activities” (ACC, 2009). All of this information is required for the development of a proposed program. In order to continue development and analysis of a material solution, authorization to do so must be received by the Milestone Decision Authority (MDA). For the EWD, a material solution is being reviewed; therefore, the Commanding General of Marine Corps Systems Command (CG, MCSC) authorized movement into the Technology Development Phase as the MDA for Milestone A.

4. Technology Development Phase

In this phase, work begins on the draft CDD, which includes the Key Performance Parameters (KPP). KPP are the “attributes or characteristics of a system that are considered critical or essential to the development of an effective military capability” (ACC, 2009). They are linked directly to the capabilities originally outlined in the ICD. KPPs serve to guide the development, demonstration, and testing of the current material solution being tested.

This thesis work fits into the Technology Development Phase. With the ICD and draft CDD, prototype development can begin. Prototype development begins with a focus on the users’ needs. In developing a prototype EWD, the targeted user is a MEU

preparing for deployment. They undergo R2P2 training in preparation for mission planning while deployed. This work recommends a flexible visualization tool to animate missions during rapid planning. In order to show the feasibility of this recommendation, JCIDS guides development of the material solution. First, user needs are identified and system performance specifications outlined. These specifications guide the creation of a demo, which is ultimately validated. Upon validation, the users' needs are then re-addressed.

Prototype development is not limited as there can be numerous in production simultaneously. The results from prototype development, demonstration and testing are contained in the final CDD. Next step is submission of the final CDD to the MDA for the Milestone B decision. The MDA reviews the CDD and performs an analysis of alternatives. Once the MDA makes a Milestone B decision, the selected material solution enters the Engineering and Manufacturing Development (EMD) Phase.

5. Engineering and Manufacturing Development (EMD) Phase

During the EMD, a fully integrated system supporting the material solution is developed. The work in this phase goes well beyond prototype development. The manufacturing process is reviewed to ensure affordability and producibility of the system. Small-scale operational suitability tests are conducted to ensure both effectiveness and a small logistics footprint. Usability with a focus on human systems integration is tested to determine additional operational requirements not recognized in prototype development. Finally, system safety and security are reviewed continually through overall system development. The results and finding during this phase are reported in the Capabilities Production Document (CPD). The CPD outlines the production requirements for a material solution found in the EMD. The CPD is finalized “after design readiness review when projected capabilities of the increment in development have been specified with sufficient accuracy to begin production” (ACC, 2009). The MDA for Milestone C then reviews the CPD and may authorize movement into the Production and Deployment Phase. If authorized, a program can then begin Low-Rate Initial Production (LRIP) and Initial Operational Test and Evaluation (IOT&E). Marine Corps Operational Test and

Evaluation Activity (MCOTEA) perform the testing and evaluation during the Production and Deployment Phase. MCOTEA supports the “material acquisition process established by MCO P5000.22” (MCOTEA, 2009).

Understanding the roles of these key organizations can enable better collaboration leading to the best decision on how to utilize the EWD to support Navy and Marine Corps amphibious training. As this work is currently in the Technology Development Phase, there is still much additional work required in order for the modernized EWD to become fully funded. The relevant merits and capabilities of EWD Modernization deserve to be fully executed according to the JCIDS process. Figure 48 shows a simplified diagram of the JCIDS process described in this section.

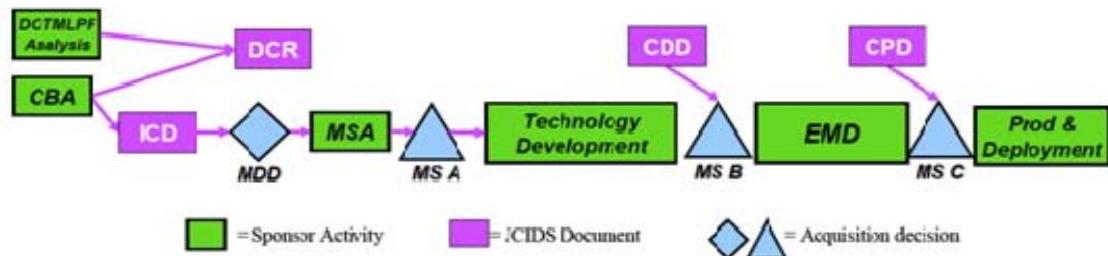


Figure 48. Diagram of the Interrelationship of JCIDS and Acquisition Processes (From JCIDS Manual, 2009)

C. INTERPRET USER NEEDS FOR MODERNIZED EWD

Currently, the EWD is not used for amphibious training. It is solely a demonstration tool showing the complex coordination required for successful amphibious landings. The EWD has the potential to become a staff and small unit trainer for the Marine Expeditionary Unit (MEU). The MEU participates in a 26 week Prepdeployment Training Program (PTP) where they are evaluated on performance of 12 different missions. A common thread through all of those missions is the previously introduced R2P2 planning cycle. This work proposes enhancing visualization during mission planning for R2P2. In order to understand users’ needs, the following section outlines the MEU’s PTP and lists the 12 missions evaluated during the PTP. Finally, it presents a list of mission essential tasks a MEU is expected to be able to perform once deployed.

1. Marine Expeditionary Unit (MEU)

The Marine Expeditionary Unit (MEU) is a Marine Air Ground Task Force (MAGTF) forward deployed and ready to respond to any crisis abroad. It is comprised of a Command Element (CE), Ground Combat Element (GCE), Air Combat Element (ACE), and a Combat Service Support Element (CSSE). There are three MEUs on each coast and one based in Okinawa, Japan for a total of seven. A MEU is commanded by a Marine Colonel. Prior to deployment, it integrates with an Amphibious Squadron (PHIBRON) and together they form an Expeditionary Strike Group (ESG). The focus of this user needs analysis for the EWD is the MEU.

The MEU has four core capabilities: Amphibious Operations, designated Maritime Special Operations, Military Operations other than War, and Supporting Operations to include the introduction of follow-on forces (USMC, 2004). Rapid planning and execution are the hallmark of the MEU. This skill can be attributed to the R2P2 process described in Chapter I. Introduced in the early phases of the MEU's Predeployment Training Program (PTP), this process guides all missions that the MEU executes.

2. MEU Mission Essential Task List (METL)

The Mission Essential Task List (METL) contained in MCO 3120.9B guides the MEU Special Operations Capable (SOC) certification program conducted during the PTP. Headquarters, U.S. Marine Corps (HQMC) provides these guidelines in order "to meet the National Command Authority and Geographic Combatant Commanders requirements for a certified, versatile MAGTF that provides a sea-based, forward presence with inherent operational flexibility to respond rapidly to multiple missions" (USMC, 2004). Once a MEU is certified, decision-makers (military and diplomatic) can use the METL to tailor an effective response to a real crisis.

The MEU Mission Essential Tasks ensure consistent capabilities across all seven MEUs and are listed below.

1. Amphibious Assault
2. Amphibious Raid

3. Amphibious Demonstration
4. Amphibious Withdrawal
5. Direct Action Operations
6. Tactical Recovery of Aircraft and Personnel (TRAP)
7. Security Operations
8. Humanitarian Assistance/Disaster Relief (HA/DR)
9. Noncombatant Evacuation Operations (NEO)
10. Peace Operations
11. Provide Command, Control, Communications, and Computers
12. Fire Support Planning, Coordination, and Control in a Joint /Combined Environment
13. Limited Expeditionary Airfield Operations
14. Terminal Guidance Operations
15. Enhanced Urban Operations
16. Enabling Operations
17. Airfield/Port Seizure
18. Employ Non-lethal Weapons
19. Tactical Deception Operations
20. Information Operations
21. Intelligence, Surveillance, Reconnaissance (ISR)
 - a. Reconnaissance and Surveillance
 - b. Counterintelligence
 - c. Signals Intelligence
 - d. Sensor Control and Management Platoon
22. Anti-terrorism
23. Rapid Response Planning Process

Considering these METLs closely, a modernized EWD can potentially enhance geospatial visualization and coordinated situational awareness (SA) to plan and train for each of these tasks. Visualization and rehearsal is possible for all tasks. This might be especially valuable when multiple tasks are being conducted in parallel. Given the open source software requirement for the EWD, animated scenarios can be created applicable

to all of these tasks. Each new scenario (3D models, terrain, entity tactical behaviors, etc.) can be placed in a resource repository for use by a follow-on unit.

3. Predeployment Training Program (PTP)

a. MEU Missions Evaluated During PTP

The PTP allows a MEU Commander with the Amphibious Squadron (PHIBRON) Commander to systematically analyze, develop and evaluate the integrated capabilities of the PHIBRON and MEU (USMC, 2004). It gives the MEU ample opportunity to enhance interoperability with the Carrier Strike Group, Joint Task Forces, Unified Combatant Commanders and civilian agencies (2004). Marines normally report to a MEU at least eight months prior to deployment. They normally report in with significant progress already completed on their Individual Training Standards (ITS). With this specific level of proficiency, the PTP is able to bring together all elements of the MEU to conduct integrated training. The integrated training is always planned through R2P2.

Integration between the MEU and PHIBRON is not the only focus of the PTP. The MEU also needs to focus on integration with Joint Task Force and Fleet Operations. In addition, the strike aircraft assigned to the Carrier Strike Group (CSG) offer the MEU an additional asset to employ combat power ashore. The MEU must be able to develop a good working relationship with the CSG to ensure good command and control to support specific MEU missions. Finally, the MEU needs to integrate with the PHIBRON's Naval Special Warfare (NAVSPECWAR) Detachment during the PTP. With all of these agencies working in close concert, a modernized EWD offers an advanced visualization tool that can help define, rehearse, and play out all missions prior to actual execution. Completed exercises and operations might also be re-enacted for in-depth team analysis and after action review (AAR).

The missions formally evaluated during PTP are listed below:

1. Amphibious Raid (boat, helicopter, and mechanized)
2. Non-combatant Evacuation Operation (single and multi-site)
3. Security Operations (area and physical security to embassy or consulate-type facility)

4. Tactical Recovery of Aircraft and Personnel (TRAP)
 5. Direct Action Mission (destruction or recovery operations)
 6. Humanitarian Assistance/Disaster Relief (HA/DR)
 7. R2P2
 8. Intelligence, Surveillance and Reconnaissance (ISR)
 - a. Reconnaissance and Surveillance
 - b. Counterintelligence
 - c. Signal Intelligence
 9. Long Range Raid (requiring Forward Arming and Refueling Point (FARP) operations)
 10. Mass Casualty (evaluation of PHIBRON/MEU medical capabilities)
 11. Airfield/Port Seizure Operations
 12. Maritime Special Operations (either as an independent, Maritime Special Purpose Force (MSPF) mission, or together with the PHIBRON NavSpecWarDet)
 - a. Gas and Oil Platform (GOPLAT)
 - b. Visit, Board, Search and Seizure (VBSS)
- b. Marine Corps Combat Readiness Evaluation Standards (MCCRES)***

MCCRES establishes Mission Performance Standards (MPS) for specific Marine Corps missions. Marine Corps Order (MCO) 3501.8A provides sample missions for use by MAGTF units to assess combat readiness. These samples can be used to establish training goals and programs to specifically get ready for formal evaluations. Prior to deployment, the MEU engages in the SOC certification during PTP and these MCCRES standards offer a baseline for preparation and evaluation.

MCO 3501.8A provides numerous MAGTF specific scenarios for unit use. For this work, Task 7A.1.1 (Conduct Amphibious Staff Planning) was most applicable for determining applicability of the EWD to MEU training. This task lists forty-six specific skills to evaluate. Of those forty-six skills, eight can be trained within the EWD. Those skills are listed and numbered below as they appear in MCO 3501.8A.

12. Identify and recommend landing sites, and concurrently prepare Commander Landing Force (CLF) mission statement for joint Commander, Amphibious Task Force (CATF)/CLF decision
20. Select a proposed beachhead simultaneously with the selection of LF objectives, and submit proposal to the CATF for review.
21. Evaluate the tentative landing sites, and select with the CATF's concurrence, primary and alternate landing areas.
22. Coordinate a decision brief for the commander on a specific landing beach within the beachhead based on the recommendations of the GCE.
23. Coordinate a decision brief by the GCE and ACE staff on proposed helicopter landing zones to include approach and retirement lanes, and control measures.
24. Coordinate a decision brief for the commander on proposed drop zones and landing zones during joint operations, when airborne or air transported joint forces are involved.
26. MEU CE develops and briefs proposed courses of action.
30. Prepare a graphic presentation of MEU concept of operations ashore in broad outline, to include task organization, and issues the concept as an outline plan.

D. CONCLUSIONS

Understanding user requirements and awareness of how work fits into a larger acquisition process is critical for any successful development program. The EWD work described in this thesis fits into the Technology Development phase of the JCIDS process. Ongoing updates to decision-making organizations within the development process are critical to ensure capability needs identified at the beginning of the process are being met. Since the MEU is expected to be the primary user of the modernized EWD, it is necessary to take time to fully understand its training requirements. EWD modernization capabilities have significant merit and deserve further advancement efforts under this process.

E. SUMMARY

This chapter briefly covers the JCIDS process and the key decision-makers that oversee the process. Also, the MEU's PTP is covered in detail to show how they are evaluated prior to deployment. Finally, the MCCRES is introduced to show the preparation guidance provided by HQMC for MEUs to prepare for SOC certification.

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VII. IMPLEMENTING MULTIPLE TECHNICAL RECOMMENDATIONS INTO A MODERNIZED EWD

A. INTRODUCTION

This chapter seeks to organize all of the many relevant technology recommendations that have been identified and address how they can best be implemented within the modernized EWD. First, the spectrum of reality is discussed and where the EWD fits into this spectrum. Second, a proposed training methodology is described that can effectively leverage the flexibility of web-based 3D visualization. Third, a 3D model of the EWD is presented to show two possible configurations of the facility. Additionally, a method is proposed to view the projected visualizations created in Chapter IV. Finally, the hardware and networking equipment needed to enable the projected display is presented with an initial cost assessment.

B. EWD WITHIN THE VIRTUALITY CONTINUUM

When implementing virtual environments for tactical training, it is important to understand where the proposed display fits into to virtuality continuum (VC). The VC ranges from completely real to completely virtual, as shown in Figure 49 (Milgram et al., 1994). Virtual reality (VR) is a completely synthetic environment where the user is completely immersed in a 3D environment. Augmented reality (AR) differs by allowing the user to see the real world with virtual objects superimposed to enhance the user's perception of the real world (Azuna, 1997). AR displays information that the user cannot directly display with his/her own senses and helps the user perform real world tasks. Between AR and VR is mixed reality (MR). MR is the combination of images from the real world with rendered images from virtual worlds (Freeman, Steed, & Zhou, 2005). This is an accurate description of the proposed implementation of X3D Earth models created from actual satellite imagery with high fidelity 3D models to create tactical scenes ashore for amphibious training in the EWD. In addition, the maritime display

proposed for the EWD is also mixed reality by using projected littoral X3D Earth models and physical SunSPOT ship models. Moving forward with the recommendations in this thesis is likely to create the largest MR application ever created.

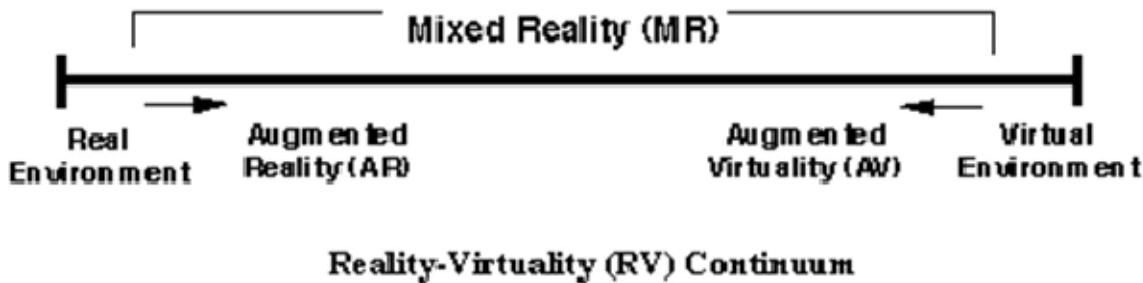


Figure 49. The Virtuality Continuum showing the EWD is a Mixed Reality Display (From Milgram et al., 1994)

C. TRAINING METHODOLOGY

Since the technology recommendations within this thesis require detailed planning prior to implementation, significant preparation time is required of Marines and Sailors prior to reporting to the EWD for MEU PTP. Preparation is required in two areas. First, there needs to be a certain level of proficiency met by the entire MEU staff on the conduct of amphibious operations prior to arrival. Computer-based training on amphibious skills is recommended to ensure they are ready to participate in Rapid Response Planning Process (R2P2) training using the large-scale visualizations shown at the EWD. Viewing 3D visualizations to drive mission planning are only effective if the viewer has some understanding of the detailed planning and coordination required. This proficiency can be tested through a pre-examination on basic amphibious skills. If a certain standard is not met, additional computer-based training can be recommended until a standard level of proficiency is met. Once ready, specific members of the MEU staff can focus on developing visualizations for their training.

To develop visualizations, only a handful of Marines and Sailors from the MEU need to learn to use the technologies recommended in this work. The most critical skill is the development of realistic scenarios on a desktop at their command prior to arriving for training. The open source requirement recommended for this work makes development

easier since there will be a community of users within the military available to assist with development. In addition, it enables sharing of tactical visualization scenarios. Once the scenarios are developed, they must also be tested to ensure the projections meet unit training objectives. The EWD staff needs to provide guidance on scenario development and offer assistance throughout the process. In addition, EWD staff will be required to test the developed scenarios performance on the large-scale display prior to approval for use in training. Since most using units will not be based from NAB Little Creek, a great deal of this collaboration needs to be conducted online.

D. X3D MODEL OF THE EWD

Recognizing that there are many options to reconfigure the aging EWD, its current state is used as a framework and starting point for this work. Today, the EWD serves as a demonstration tool by using physical models to visualize amphibious operations. Currently, observers sit back and watch a single realistic scenario from initial warning order to mission completion. At no time are they engaged or required to critically think and make the many complex decisions that are needed to conduct the scenario. This work seeks active participant engagement and participation to facilitate amphibious training. In consideration of the Commandant's directive documented at the beginning of this thesis, active duty Marines and Sailors need to maximize any and all training opportunities because of the current tempo of operations. This is the best argument to convert the EWD from a demonstrator to an amphibious operations trainer. An important question regarding facility layout then arises. Should the EWD remain in its current configuration as a demonstrator or should it be modified to support MEU staff and small unit training?

To better visualize options, a 3D model of the EWD was created. The primary source for data to create this model was the large collection of blueprints used for the original construction in 1953. Some scanned examples of the blueprints can be found in Appendix E. During a site visit to the EWD in August 2008, the blueprints were reviewed and compared to the actual building structure. Multiple photographs were taken for further study while modeling. Over the past 50 years, some additions and modifications

were made, but none impacted the demonstration or seating area. After careful examination of the blueprints and the facility, modeling of the structure began.

Using a step-by-step approach, the EWD's current configuration was the first modeling task. The exterior structure was the first portion modeled. Next, the large-scale demonstration table with the adjoining projection screens was added. The office area at the front of the building followed. Finally, the lights and catwalks were positioned directly above the demonstration table. The lights and catwalk were the most critical portions of the model because they determined projector placement for the proposed projection of X3D scenes. By recognizing this limiting factor, visible viewpoints were added to the model to show the coverage of each of the twenty proposed projectors for the demonstration area. Figure 50 shows the final model in the Octaga browser.

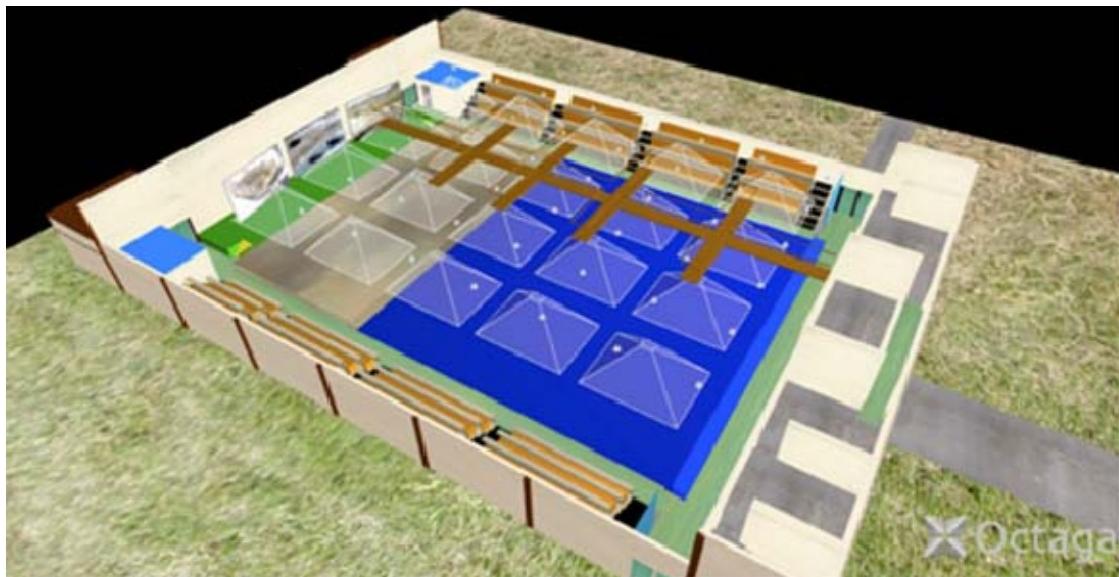


Figure 50. Final Model of the EWD Authored in X3D

After completion, the model was forwarded to PMTRASYS for review and used for discussion regarding layout. All key-players in the modernization effort from PMTRASYS, TECOM and NAWC-TSD were familiar with the facility; however, the model still served as an essential collaboration tool. As new facility configuration ideas emerged, the X3D model was modified and compared to previous versions.

E. TWO RECOMMENDED OPTIONS FOR FACILITY LAYOUT

1. Modernize and Retain Current EWD Configuration as a Demonstrator

Maintaining the current configuration is the lowest-cost solution available. In this configuration shown in Figure 51, projectors are placed over the display area to project the complete littoral waters adjacent to the landing beach and surrounding terrain ashore. The surface size remains intact at 96 by 69 feet; however, the surface itself is replaced with a finished surface to enable proper viewing of the projected X3D scenes. The current ship models driven by the electrical pulleys are removed and replaced by the SunSPOT-driven ship models. Finally, the seating remains unchanged.

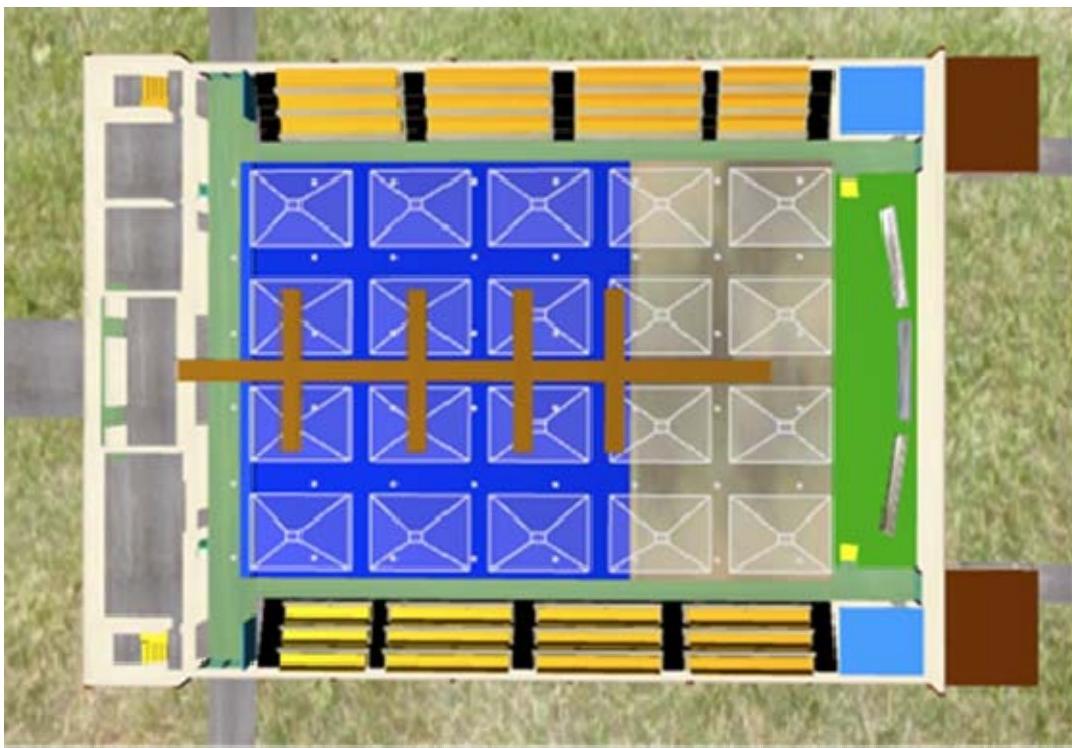


Figure 51. Top View of X3D Model of the EWD Showing the Overhead Projection Recommendation

One interesting consideration when retaining the current configuration is the usage of the catwalks for viewing of projected displays during training. This gives commanders a “bird’s eye” view of terrain and maneuvers during training or mission rehearsals. Considering this capability, cross-community rehearsal and training between

multiple specialties (USMC, Surface Warfare, Air Support) can be more effective. In addition, this opportunity to view the battlefield from another perspective can be a critical tool in the development of new doctrine or tactics. Such an opportunity for combined Marine Corps and Navy training and tactical planning does not yet exist and likely will enable significant progress in amphibious operation tactical development.

2. Modernize and Change EWD Configuration as a Trainer

The second option for modernizing the EWD changes the configuration to enhance interaction among Marines and Sailors observing amphibious maneuvers. The configuration shown in Figure 52 is recommended to convert the EWD from a demonstration tool to a training tool. In the current demonstrator configuration, there is little opportunity for real interaction since the seating arrangement is restrictive. It is not practical for Sailors and Marines to walk freely across such a large display area to discuss mission execution options. If converting the EWD into a trainer vice demonstrator becomes a priority, this option best supports small-group plus large-group training with staff interaction.

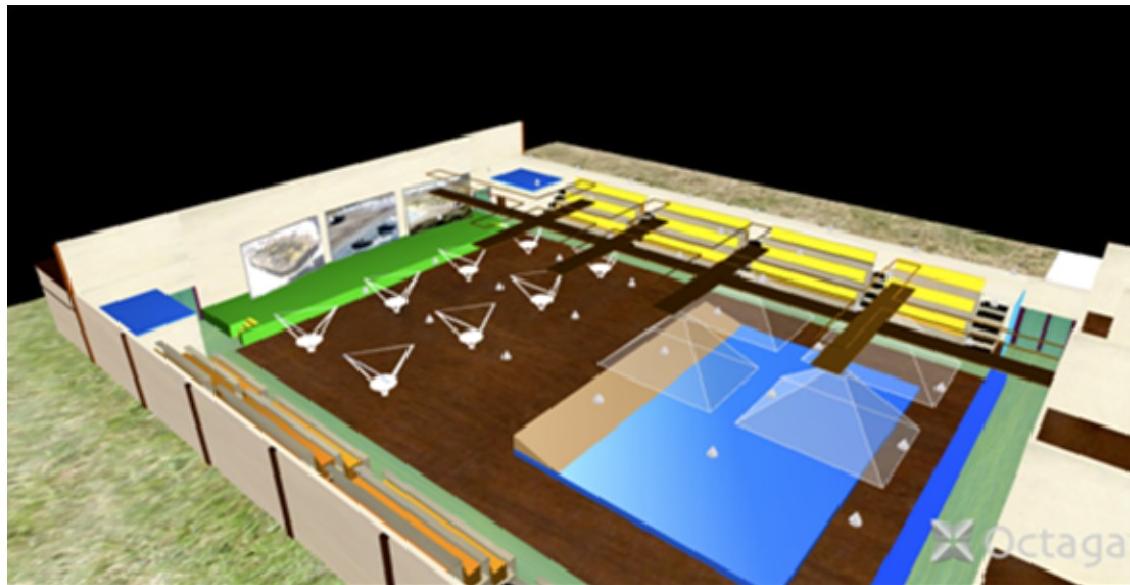


Figure 52. Model of the EWD Showing Configuration Change Recommendation to Enhance Interaction during Training

a. Improved Layout to Enhance User Interaction

This option has a large display table, but it is reduced in size. The new size recommended in this work is 60 by 48 feet. This layout will provide open space for MEU staff to walk around the display table and observe imagery from multiple perspectives. With the additional space added, multiple virtual sand tables are recommended near the three screens shown in Figure 53. The sand tables currently in use for the BASE-IT project are applicable for use in the EWD. These tables would enable viewing of same mission scenarios displayed on the large demonstration table as shown in Figure 50. In addition, they can be also be used for Marine Infantry Squad training as described in Chapter II.

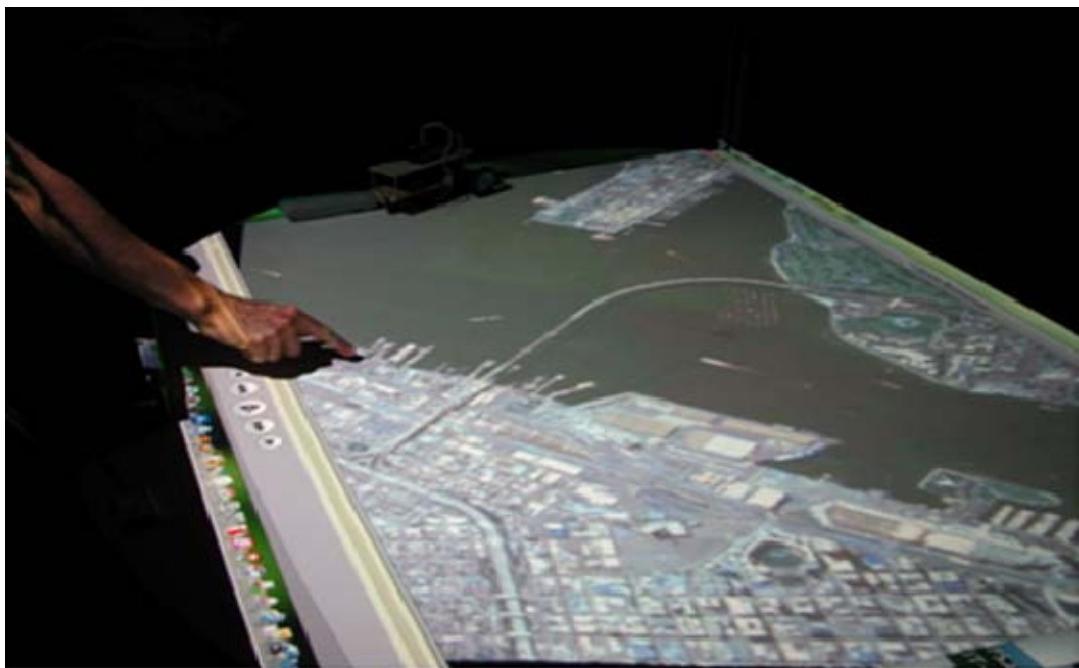


Figure 53. Animated X3D Earth Scene of San Diego Harbor Displayed on BASE-IT Virtual Sand Table

This same virtual table can be used to display 3D holograms of the target objective area for training and mission planning. This technology previously described in Chapter V requires one simple modification to the BASE-IT virtual sand table. One green lens light needs to be added in order to illuminate the hologram correctly. The light pictured in Figure 54 can easily be clamped to the overhead structure of the BASE-IT

table to support training. This light retails for \$1000. Its high cost is due to the lack of availability of high intensity, green lens lights from most lighting vendors.



**Figure 54. Lighting Required to Be Clamped to BASE-IT Virtual Sand Table to Enable Viewing of 3D Holograms at EWD
(From Zebra Imaging, 2009)**

To test the concept of reducing the size of the demonstration table, a proof of concept at 16% scale (12 feet by 8 feet) was constructed at NPS to display naval maneuvers and ship positioning in support of Marines as they move ashore. The focus of this effort was to allow users to move around the display surface holding SunSPOT controllers while they maneuvered their specific ship model. The proof of concept shows the flexibility and smooth movement of the new ship models with balsa wood hulls placed on top. A smaller display table than what is currently used at the EWD would allow greater opportunity for interaction between the staff while also allowing all key players an opportunity to clearly see planned movements of ships to support amphibious operations. Overhead projected X3D Earth imagery is used at the modernized EWD, but is not shown in this prototype. Tactical symbology, transit lanes, identifying designators, sensor footprints, tactical parameters and other amplifying information might all be superimposed to illustrate the scenario and improve situational awareness. This prototype has a removable white surface that can be replaced for future testing of overhead projections. The proof of concept is shown in Figure 55.



Figure 55. Maritime Training Table Prototype Created at NPS for EWD to Display SunSPOT-controlled Ship Models

b. Proposed Modeling and Simulation Center for Excellence

Considering the recommended configuration changes for the EWD in option two, a further upgrade can be the addition of training on additional simulation software during the PTP. In the new configuration, a designated area within the EWD can be used for hands-on-training using the Deployable Virtual Training Environment (DVTE). The DVTE is:

...a first person skills sustainment trainer that trains Marines by using a simulation network with reconfigurable workstations capable of emulating a variety of weapon systems. Individuals select the weapon, vehicle, or leadership billet desired, then join a virtual battle space where others and synthetic forces are engaged in virtual operations. Individual MAGTF skills can be trained in this virtual environment using a Semi-Autonomous Force (JSAT) model as its basis. (DVTE, 2009)

Marines can be provided the opportunity to gain practical application on the DVTE, and staff leadership can be actively challenged and critiqued on the production of training scenarios within the suite. Overall, this gains further exposure for DVTE and offer the training development community another location where it is possible to collect effectiveness data to improve the software.

F. HARDWARE REQUIRED TO RETAIN CURRENT DEMONSTRATOR CONFIGURATION

Retaining the current configuration is quickest solution towards modernizing the EWD and supporting the CMC's strategic directive. This section briefly covers the characteristics of the type of projector needed for this work. Also covered are the network requirements proposed for the distributed display. These solutions can enable implementation of the technology recommendations contained in the previous chapters. This section concludes with a cost-analysis table outlining the total cost for all hardware for demonstrator modernization if this option were selected.

1. Projector Considerations

A select number of high-performance, commercial off-the-shelf (COTS) projectors are available to meet the EWD's projection needs. The recommended projector needs to be capable of meeting the unique setup and viewing requirements for the EWD. First, due to the complexity of the projected animations, a projector with a contrast ratio of at least 1,000:1 is needed. Contrast ratio is the ratio of luminance between the brightest light (white) and the darkest light (black), allowing a user to discern objects and their movement within a scene more clearly (Majumder & Brown, 2007). A projector with such a high contrast ratio produces the clearest and sharpest projections. Second, a projector with a low throw ratio (between 1.15 and 1.8) is required to minimize the number of projectors required in the high-bay overhead space. Throw ratio is the ratio between the projector's distance from the projection surface and the width of the projection (Majumder & Brown, 2007). Third, the projector has to emit at least 3,500 lumens due to the overall size of the building. A high lumens value also offers the capability of displaying scenarios with some limited overhead lighting (Majumder & Brown, 2007). Finally, projection needs to support at least 1,024 x 768 pixels to ensure clarity of the image and models within the image. Higher preferred resolutions using current COTS hardware for generation and projection include 1600 x 1200 and 1280 by 1024.

A number of models were considered during the spring and summer of 2009 before recommending the Epson Powerlite Pro G5150NL. This projector satisfied all of the requirements outlined previously and met strict industry reliability standards. This particular projector is used in the cost analysis shown in Table 3. A review of projectors considered for this work is contained in Appendix F. This survey will need to be repeated before final procurement. Projector capabilities and price-performance value continue to improve steadily.

2. Network Considerations

A proposed network configuration to support the tactical visualization multiple projectors was also devised. A single laptop serves as control station to drive all of the mission scenarios. This control station is connected to a server that stores all X3D Earth models, AMEX models and previously developed scenarios. An architecture of one router and five switches connect the control station laptop with twenty MacMINIs. The MacMINIs are used to drive the multiple projector displays with its embedded NVIDIA GeForce 9400M graphics card. Using Apple's Remote Desktop 3.3 on the control station, portions of the mission visualization can be selected for display on a specific MacMINI within the network. Connected to each of the MacMINIs is a SunSPOT base station. This is used as a wireless access point to ensure the NPS robots can freely move throughout the entire display area. The concept for the networked display system is shown on a small scale in Figure 56.

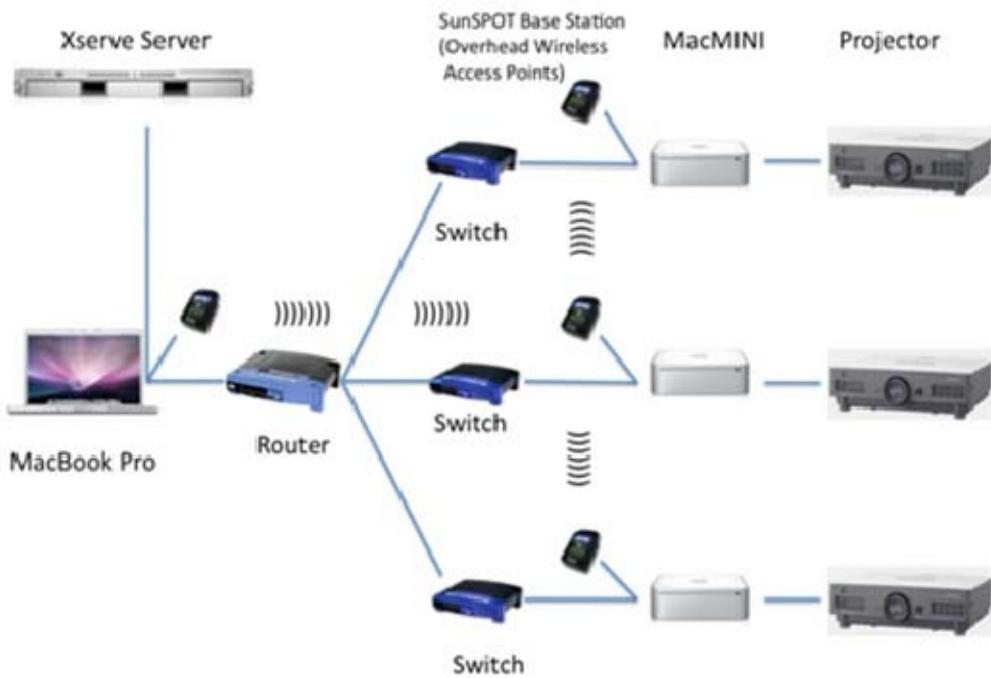


Figure 56. Proposed Network Architecture for Distributed Overhead Projector Display for Modernized EWD

3. Cost Analysis

The cost analysis is normally one of the most important factors to determine a specific acquisition decision. The data presented in Table 3 includes the number of projectors required based on throw ratio, the distance from the display surface, and the size of the display surface. This cost analysis includes the necessary networking hardware described in the last section. An uninterruptible power supply was added to the required hardware list in order to ensure consistent, steady power to each of the components. In addition surge protectors were also added to the hardware list, but were not shown in Figure 56. The lowest prices found were used in this analysis. For example, the Epson Powerlite Pro retails for \$4099, but the projector was found online for \$2189. The link can be found in Appendix F.

Table 3. Cost Analysis for EWD Modernization as a Demonstrator (No Change in Configuration)

Item	Number	Cost per Item	Total Cost
Epson Powerlite Pro G5150NL Projector	20	\$2189	\$43,780
MacMINI Processor for Projectors	20	\$599	\$11,980
MacBook Pro Control Station	1	\$2999	\$2999
Linksys Cable DSL/Router with 8 Port Switch	1	\$97	\$97
Linksys EZXS55W EtherFast 10/100 5 Port Switch	5	\$15	\$75
CAT-6 Ethernet Cable (1000 Ft)	1	\$150	\$150
XServe Server for Software Application Storage	1	\$3599	\$3599
Dell 15000 Watt Uninterruptable Power Supply	1	\$4333	\$4333
Belkin 6 Socket Surge Protector	20	\$11	\$220
SunSPOT Wireless Access Points (Base stations)	5	\$225	\$1125
Total Projected Cost			\$68,353

G. OVERHEAD PROJECTION

Overhead projection was selected for this work to more cost effectively use digital terrain data with wargaming tables. In order to obtain the necessary data to project an overhead display, some processing is required. This section presents the processing solution recommend and also details ongoing research on multiple cinematography upgrades recommended for X3D that may benefit this work.

1. Digital Cinematography

At this year's Web3D Symposium, the concept of adding X3D <Camera> nodes was considered and work to implement this functionality has already produced functioning prototypes (Weekley & Brutzman, 2009). Presenting dynamic tactical visualizations are usually most effective when the viewer can see the scenario unfold from the proper perspective. The challenge of presenting the right scenes and ensuring that viewers are able to discern the activity presented lies with the director of the visualization. At the beginning of this thesis, the term creation was used to refer to the

development of a tactical animation. It is more effective to say that a Marine or Sailor is required to direct the production of a tactical visualization. The proposed <Camera> node recommends adding “camera movement, movement sequencing, field of view, aperture control, focal length, focal distance and camera aim” (Weekley & Brutzman, 2009). These nodes can enable a Marine or Sailor to create the exact scenario required for unit training by editing a storyboard corresponding to the simulated action (Nicklaus, 2008).

An additional recommendation was also covered with the addition of the <Camera> node. The <OfflineRender> node was proposed as a method to record video within an X3D scene (Weekley & Brutzman, 2009). For this work, Screen Record 2.1.2 was used to obtain movie files of the tactical scenarios. Adding the <OfflineRender> node may make it easier to record tactical scenarios as movie file outputs. The processing step is discussed in the next section.

2. Processing Movie File

As a proof of concept regarding the value of digital cinematography for EWD scenario playbacks, the Open Computer Vision (OpenCV) libraries were used to modify movie files produced in X3D. Appendix D contains the source code for this processing. The code written is for a four-projector solution, but it can be modified to add additional projectors. Essentially, the code loops through a movie file and identifies regions of interest within the input movie file. The upper left portion of the region of interest is specific along with the area of the region. Once defined, a window can be created to show that portion of the display. In this work, that is the portion that is displayed through the MacMINI. The code shown in Figure 57 shows how a region of interest are defined for the upper left portion of video.

```
// Upper Left
CvRect rectUL = cvRect(0, 0, cvRound(( frameUL->width - 1) / 2),
                      cvRound((frameUL->height - 1) / 2));
cvSetImageROI(frameUL, rectUL);
cvShowImage("EWDVideoUpperLeft", frameUL);
cvResetImageROI(frameUL);
```

Figure 57. OpenCV Code Showing How to Set a Region of Interest in a Movie File Showing an X3D Tactical Scenario

After processing, the entire display appears as shown in Figure 58. This snapshot was originally shown in Figure 39. The figure shows an animated aircraft moving between regions of interest. Future work is recommended in this area to ensure no loss of fidelity along the seams of a projected display. Much recent progress has been made in constructing seamless multi-screen displays at low cost using normal projectors adjusted by real time video feedback (Towles, Johnson, & Fuchs, 2009).



Figure 58. Processed Movie File Showing Four Regions for Display by Overhead Projector

3. Seamless Rendering in the EWD

For a display as large as the EWD, multiple projectors are required to form a single display that is geometrically and photometrically seamless from the users' perspective. The geometric considerations include position and slope discontinuities, while the photometric considerations include detection of increased brightness along the seams and color differences between projectors (Towles, Johnson, & Fuchs, 2009). Since the EWD is a flat planar surface, additional processing due to image warping are not required. However, blending techniques do need to be applied to compensate for the higher photometric intensity observed in the projector overlap region. "Two blending techniques are commonly used to compensate for this luminance gain are electronic

attenuation of the input signal or the placement of a physical aperture mask in the optical path” (Towles, Johnson, & Fuchs, 2009). There are several companies that produce warp and blend products including Rockwell Collins and 3D Perception. Specifically, Rockwell Collins has DigiBlend, which can adjust color balance and blend edges (“Rockwell Collins,” 2009). Further investigation and future testing of multiple blending solutions is recommended.

H. CONCLUSIONS

This thesis recommends many potential technology upgrades and this chapter concludes this work by discussing options to effectively implement and integrate them within the EWD. There are many challenges associated with projecting such a large-scale display, but the pay-off may be vastly improved integration between warfare communities. When implemented correctly, tactical visualization may bridge the communication gap existing between Marines and Sailors in different warfare specialties. Allowing them to view tactical visualizations together and discuss operations while they are occurring can greatly enhance their combined training and readiness. This work strongly recommends the EWD become a test bed for 3D visualization to enable warfighters to develop, view, and train with tactical scenarios. It is only a matter of time that 2D imagery will be replaced with 3D visualization tools. Modernizing the EWD is a cost-effective way to speed up that process for amphibious warfighters.

The technology upgrades outlined in this thesis can be implemented into two proposed facility configurations. The first option is as a demonstrator with the added flexibility to create multiple tactical scenarios using projected X3D scenes. The second option is as a trainer, which encourages interaction by reducing the size of the EWD display surface, adding smaller virtual sand tables and opening the overall display floor for movement and collaboration during training. Both options are feasible with a high probability of success. Implementation of these technologies can occur in a staged manner to ensure continued availability of the current demonstrator during construction.

I. SUMMARY

This chapter organizes the technology recommendations identified in this thesis and addresses how they can best be implemented within the modernized EWD. The virtuality continuum is presented to show how the EWD fits into this spectrum. Then, a proposed training methodology is described that can effectively leverage the flexibility of web based 3D visualization. For future collaboration, a 3D model of the EWD is presented to show two possible configurations of the facility. Additionally, a method is proposed to view the projected visualizations created in Chapter IV. Finally, the hardware and networking equipment needed to enable the projected display is presented with an initial cost assessment.

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VIII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

There are several different training applications that arise from the use of the technologies recommended for the modernization of the EWD. Multiple conclusions and recommendations for future work follow.

1. Rebuild the EWD

The EWD in its current configuration limits training due to the inflexibility of the naval surface movements and the fixed terrain display. Although these limitations exist, many units still use the EWD for their training. Recently, as shown in Figure 59, international officers attending Marine Corps' Command and Staff College observed the hour-long scenario and felt the training received was effective, but also pointed out that EWD can be expanded. This thesis shows that there are many technologies available to enhance the EWD to meet future amphibious training needs. The existing facility is sound and can be upgraded significantly in an economical way since no building modifications are needed.



Figure 59. International Officers from USMC's Command and Staff College Observe Amphibious Scenario on 1 September 2009

2. Enhanced 3D Visualization

Enhanced 3D Visualization has the potential to improve staff planning and overall mission situational awareness. The MEU operates in all three dimensions because they typically rely on combined arms to support operations ashore. Airspace and mission timelines are all meticulously planned prior to execution to ensure safety. Safety is of utmost concern since Marines seek to strike their enemies immediately following impacts from naval gunfire, close air support strikes, or artillery fire. Airspace and time restrictions eliminate the threat of fratricide and enable the most effective employment of supporting arms. 3D geospatial visualization allows a staff to visualize these missions and the complex coordination required before they occur, as well as provide a visual feedback (visual information) interactively from any viewpoint inside that space, including ground level. 2D imagery and maps are still the primary planning tools used for these missions today. Unfortunately, 2D media fails to provide the critical visualization information that is readily available with 3D tools. This thesis shows the process of producing a range of useful 3D visualizations to support real-world missions. Recognizing their value and applying them to predeployment training is critical in order to expose Marines and Sailors to the best visualization tools available to support future mission planning.

3. Wireless Control Devices

Wireless control devices can improve user interaction during training. Sun Microsystems' SunSPOT, a low-cost sensor with a wireless communications capability, was used in this work to create robotic ship models designed to recreate a maritime common operational picture prior to an amphibious landing. This is only one application. The device has numerous real world and training applications that are only limited by a user's imagination. During the user study, Marine subjects were intrigued by the device and throughout the study offered creative advice on how to use the SunSPOT. The device stimulated technical thought during development for everyone involved in the project. In the end, this thesis shows that wireless control devices can be applied to the EWD to visualize naval surface movements potentially encourage staff interaction during training.

4. Open Source Software

Open source software and 3D modeling tools offer a significant savings in initial acquisition and future maintenance costs. The most significant upgrade recommended for the EWD is the creation of real world enhanced 3D scenes by Marines training in the EWD. The X3D community has made a significant effort over the last year to place instructional tutorials online to enable anyone to learn how to program in X3D and create content. Also, X3D is an International Organization for Standardization (ISO) standard, so models and scenes created long ago are still viewable today. Thus, the scenes created now for the EWD will continue to be available years from now. The EWD thus become better over time as mission animations accumulate. A cost savings results from this ease of scene authoring ,further allowing the creation of large training repositories. Such capabilities are not feasible using commercial 3D software models that are encumbered by license restrictions and limited lifetimes.

5. Geospatial Visualization

Upgrading the EWD can improve geospatial operator visualization and mission understanding during R2P2. The PTP begins with instruction on rapid planning. Overall, it is not a difficult process but can be challenging due to the strict time constraints given. Planning a complex mission that integrates all of the combat power available within the MEU, then commencing plan execution within six hours from the receipt of the warning order at first seems insurmountable. Marines and Sailors over time learn how to work together to smoothly operate in concert to attack enemies from the sea. Enhanced 3D geospatial visualization introduced in the earliest stages of the PTP can improve the MEU and PHIBRON's combined learning curve and integration, making the entire process more effective. Corresponding evaluation and after action review (AAR) of completed exercises and operational missions will yield additional insight and stimulate more effective tactical development.

B. RECOMMENDATIONS FOR FUTURE WORK

1. Prototype Model of the EWD

To ensure success of the EWD modernization effort, production and development of the small-scale model of the modernized EWD must continue to enable technology testing. Multiple user studies are recommended to best test different training techniques using the SunSPOT ship models and incorporating the X3D Earth scenes. Additionally, tests must be conducted to determine time and training required for new users to develop X3D scenes. Testing a partial-scale model can also allow for testing of projector blending required for the use of multiple overhead projectors in the larger EWD facility.

2. Mission Animation Repository

Working towards creating a repository of animations in littoral “hot spots” around the globe including the Northern Arabian Gulf, North Korea, and the Horn of Africa make the EWD a more credible training facility and immediately impact the MEU’s PTP. Having a repository enables any unit to arrive at the EWD and choose from a large group of scenarios with specific training objectives. In addition, since X3D scenes can be easily modified, scenes can be changed to match a specific unit’s training objectives. Establishing synchronized network simulations at multiple display locations also enables combined training by multiple staffs to maximize interoperability and consistency. Such work is a good fit for ongoing applied research by graduate student officers at the Naval Postgraduate School (NPS).

3. BRL-CAD and X3D Interoperability

The models used for this research were developed in BRL-CAD, which is used by the Army Research Laboratory for lethality analysis. Since this work showed modifications required to export those models into X3D, further investigation on how ARL uses BRL-CAD models for analysis needs to continue in order to consider improving the functionality of X3D to possibly support similar analysis tasks. Also, this work makes multiple recommendations for improvements in the BRL-CAD exporter.

Additional partnered work must continue to improve model usage and sharing within the Army Model Exchange and other similar model repositories.

4. SunSPOT User Control Interface

The user interface on the SunSPOT ship models uses internal communication to pass data between the remote control and the SunSPOT device mounted on the ship model. During this work, a desktop user interface was also created using the SunSPOT base station to pass data to the ship models. Investigation on using the base station to move models within X3D scenes adds another level of functionality to the EWD, giving users an opportunity to move models within tactical scenes as they discuss mission options.

5. Collaboration using X3D Models

Numerous virtual environments have been tested for business collaboration to bring together geographically separated teams. Second Life, Project Wonderland, and Exit Reality are virtual environments that allow the exchange of PDF files, movie files, and 3D models (Sanders, 2007). Project Wonderland v0.4 and Exit Reality are two options to consider to enhance business collaboration for the EWD modernization project. These tools might comparably enable a 3D model of the EWD to be imported into a scene, and user-controlled avatars can then move throughout the EWD model and share ideas. This would be more powerful than a teleconference and more cost effective than business travel. Since the key players in this modernization project are located in Orlando, FL; Monterey, CA; and Norfolk, VA, virtual collaboration can improve continuity and ensure continued progress towards modernizing the EWD. Use of Project Darkstar Massively Multiplayer Online Game (MMOG) server holds particular promise (Rashid, 2009).

6. Ease Production of X3D Earth Scenes

All of the X3D scenes created for this work were produced using X3D-Edit 3.2. Although the process was relatively simple, adding some improved functionality to X3D-Edit 3.2 will improve workflow and overall productivity. Further work is recommended

to add a template for tactical X3D scenes, the ability to drag and drop AMEX and X3D Earth models into a scene, and a tool to ensure accuracy of SMAL metadata to be added to the scene. Each of these suggestions will allow Marines and Sailors to create scenes more quickly and ensures standardization, consistency, and interoperability for future re-use in training.

7. Agent Based Training Scenarios Using Discrete Event Simulation (DES)

The final recommendation is to use DES to simulate enemy activity and mission outcomes within the EWD scenarios to create a more dynamic training environment. By using the open-source tool Viskit, units can potentially enhance their mission planning, training, and analysis by simulating the effects of various inputs such as enemy unit size and duration of operation into their training scenarios (Thomas, 2008). Viskit can create a different training scenario every time the EWD is used. More importantly, the simulations can be available upon departing the EWD in any available web browser. This will give Marines and Sailors an opportunity to continually wargame scenarios and keep their amphibious readiness at a peak level. As tactical software-agent capabilities continue to improve some or all protagonists can be virtually controlled to verify the effectiveness of amphibious warfare tactics, techniques, and procedures (TTP) (Thomas, 2008).

APPENDIX A. SUNSPOT SOURCE CODE FOR SHIP MODELS

A. INTRODUCTION

Appendix A contains source code for the NPS robotic ship models. The code was developed and evaluated during a user study conducted at DLI on the Presidio of Monterey. Twenty-four Marine subjects offered quantitative and verbal feedback on the overall control of the robot. Their inputs were integrated into the codes presented below.

B. TRACKBOT CONTROLLER

```
/*
 * Name: Christian Fitzpatrick
 * File: TrackBotControllerVer2.java
 *
 * This is the fourth version of the code to receive data from a hand-held
 * SunSPOT controller, process the data by placing it into an array, and then
 * power specific pins to control the motors on the vehicle. This time we
 * have abandoned using the acceleration data along the x-axis for left and
 * right turns. This time we will attempt to use the switches on the SunSPOT
 * eDemo board.
 *
 * This code again will be tested only by developers and possibly again by
 * Marines at DLI.
 */
package org.sunspotworld;

import com.sun.spot.sensorboard.peripheral.IAccelerometer3D;
import com.sun.spot.sensorboard.EDemoBoard;
import com.sun.spot.sensorboard.peripheral.ITriColorLED;
import com.sun.spot.sensorboard.peripheral.LEDColor;
import com.sun.spot.sensorboard.io.IOutputPin;

import java.io.*;
import javax.microedition.io.Connector;
import javax.microedition.io.Datagram;
import javax.microedition.midlet.MIDletStateException;
import com.sun.spot.io.j2me.radiogram.RadiogramConnection;
import com.sun.spot.sensorboard.peripheral.ISwitch;
import com.sun.spot.util.Utils;

/**
 * The startApp method of this class is called by the VM to start the
 * application.
 *
 * The manifest specifies this class as MIDlet-1, which means it will
 * be selected for execution.
 */
public class TrackBotControllerVer4 extends javax.microedition.midlet.MIDlet {

    public ITriColorLED[] leds ;
    public IOutputPin[] outPins ;
    public ISwitch sw1 = EDemoBoard.getInstance().getSwitches() [0];
    public ISwitch sw2 = EDemoBoard.getInstance().getSwitches() [1];
    IAccelerometer3D accel;
    public double LEFT = 150;
    public double RIGHT = -150;
```

```

protected void startApp() throws MIDletStateChangeException {
    System.out.println("This TrackBot is ready to go!");
    leds = EDEmoBoard.getInstance().getLEDs();
    outPins = EDEmoBoard.getInstance().getOutputPins();
    for(int i=0;i<8;i++) {
        leds[i].setOn();
        leds[i].setColor(LEDColor.YELLOW);
        Utils.sleep(50);
        leds[i].setOff(); // Initial led test upon SunSPOT turn on
    }
    startReceiverThread();
}

public void startReceiverThread() {
    new Thread() {
        public void run() {
            double tmp = 0.0;
            double tility = 0;
            RadiogramConnection dgConnection = null;
            Datagram dg = null;

            try {
                dgConnection = (RadiogramConnection) Connector.open("radiogram://:41");
                dg = dgConnection.newDatagram(dgConnection.getMaximumLength());
            } catch (IOException e) {
                System.out.println("Could not open radiogram receiver connection");
                e.printStackTrace();
                return;
            }

            while(true){
                try {
                    dg.reset();
                    dgConnection.receive(dg);
                    tmp = dg.readDouble();
                    double tility = tmp;

                    // Returns [-90, 90], Convert angle to range [-3, 3]
                    int tility = (int) Math.toDegrees(tility);
                    int accelFB = -tility / 15;

                    // Set max forward acceleration to -90 degrees
                    if (accelFB < -3 && accelFB > -9){
                        accelFB = -3;
                    }

                    // Set max reverse acceleration to 90 degrees
                    if (accelFB > 3 && accelFB < 9){
                        accelFB = 3;
                    }

                    // Stop
                    if (accelFB == 0) {
                        outPins[EDEmoBoard.H0].setLow();
                        outPins[EDEmoBoard.H1].setLow();
                        outPins[EDEmoBoard.H2].setLow();
                        outPins[EDEmoBoard.H3].setLow();
                        System.out.println("TrackBot is stopped.");
                    }

                    // Blink Red LEDs twice to show stopped vehicle
                    for (int i = 0; i < 2; i++) {
                        for (int j = 0; j < 8; j++) {
                            leds[j].setColor(LEDColor.RED);
                            leds[j].setOn();
                        }
                        Utils.sleep(50);
                        for (int j = 0; j < 8; j++) {
                            leds[j].setOff();
                        }
                    }
                }
            }

            // Turn right
            if (accelFB > 9){
                outPins[EDEmoBoard.H0].setLow();
                outPins[EDEmoBoard.H1].setHigh();
                outPins[EDEmoBoard.H2].setHigh();
                outPins[EDEmoBoard.H3].setLow();
            }
        }
    };
}

```

```

        System.out.println("TrackBot is turning right.");
        // Blink LEDs 2 times to show right turn
        for (int i = 0; i < 2; i++) {
            for (int j = 0; j < 8; j++) {
                leds[j].setColor(LEDColor.GREEN);
                leds[j].setOn();
                Utils.sleep(50);
                leds[j].setOff();
            }
        }
        // Turn left
        if (accelFB < -9) {
            outPins[EDemoBoard.H0].setHigh();
            outPins[EDemoBoard.H1].setLow();
            outPins[EDemoBoard.H2].setLow();
            outPins[EDemoBoard.H3].setHigh();
            System.out.println("TrackBot is turning left.");
            // Blink LEDs 2 times to show left turn
            for (int i = 0; i < 2; i++) {
                for (int j = 7; j > -1; j--) {
                    leds[j].setColor(LEDColor.GREEN);
                    leds[j].setOn();
                    Utils.sleep(50);
                    leds[j].setOff();
                }
            }
            // Move backward
            if (accelFB > 0 && accelFB < 9) {
                outPins[EDemoBoard.H0].setLow();
                outPins[EDemoBoard.H1].setHigh();
                outPins[EDemoBoard.H2].setLow();
                outPins[EDemoBoard.H3].setHigh();
                System.out.println("TrackBot is moving backward.");
                // Blink LEDs 2 times to show reverse movement
                for (int i = 0; i < 2; i++) {
                    leds[0].setColor(LEDColor.GREEN);
                    leds[7].setColor(LEDColor.GREEN);
                    leds[0].setOn();
                    leds[7].setOn();
                    Utils.sleep(50);
                    leds[0].setOff();
                    leds[7].setOff();

                    leds[1].setColor(LEDColor.GREEN);
                    leds[6].setColor(LEDColor.GREEN);
                    leds[1].setOn();
                    leds[6].setOn();
                    Utils.sleep(50);
                    leds[1].setOff();
                    leds[6].setOff();

                    leds[2].setColor(LEDColor.GREEN);
                    leds[5].setColor(LEDColor.GREEN);
                    leds[2].setOn();
                    leds[5].setOn();
                    Utils.sleep(50);
                    leds[2].setOff();
                    leds[5].setOff();

                    leds[3].setColor(LEDColor.GREEN);
                    leds[4].setColor(LEDColor.GREEN);
                    leds[3].setOn();
                    leds[4].setOn();
                    Utils.sleep(50);
                    leds[3].setOff();
                    leds[4].setOff();
                }
            }
            //Move forward
            if (accelFB < 0 && accelFB > -9) {
                outPins[EDemoBoard.H0].setHigh();

```

```

        outPins[EDemoBoard.H1].setLow();
        outPins[EDemoBoard.H2].setHigh();
        outPins[EDemoBoard.H3].setLow();
        System.out.println("TrackBot moving forward.");

        // Blink LEDs 2 times to show forward movement
        for (int i = 0; i < 2; i++) {
            leds[3].setColor(LEDColor.GREEN);
            leds[4].setColor(LEDColor.GREEN);
            leds[3].setOn();
            leds[4].setOn();
            Utils.sleep(50);
            leds[3].setOff();
            leds[4].setOff();

            leds[2].setColor(LEDColor.GREEN);
            leds[5].setColor(LEDColor.GREEN);
            leds[2].setOn();
            leds[5].setOn();
            Utils.sleep(50);
            leds[2].setOff();
            leds[5].setOff();

            leds[1].setColor(LEDColor.GREEN);
            leds[6].setColor(LEDColor.GREEN);
            leds[1].setOn();
            leds[6].setOn();
            Utils.sleep(50);
            leds[1].setOff();
            leds[6].setOff();

            leds[0].setColor(LEDColor.GREEN);
            leds[7].setColor(LEDColor.GREEN);
            leds[0].setOn();
            leds[7].setOn();
            Utils.sleep(50);
            leds[0].setOff();
            leds[7].setOff();
        }
    }

    } catch (IOException ex) {
        ex.printStackTrace();
    }
}

}.start();
}

protected void pauseApp() {
    // This is not currently called by the Squawk VM
}

/**
 * Called if the MIDlet is terminated by the system.
 * I.e. if startApp throws any exception other than MIDletStateChangeException,
 * if the isolate running the MIDlet is killed with Isolate.exit(), or
 * if VM.stopVM() is called.
 *
 * It is not called if MIDlet.notifyDestroyed() was called.
 *
 * @param unconditional If true when this method is called, the MIDlet must
 * cleanup and release all resources. If false the MIDlet may throw
 * MIDletStateChangeException to indicate it does not want to be destroyed
 * at this time.
 */
protected void destroyApp(boolean unconditional) throws MIDletStateChangeException {
}
}

```

C. REMOTE CONTROLLER

```
/* Name: Christian Fitzpatrick
 * File: RemoteControlVer2.java
 *
 * The purpose of this code is to drive a hand-held SunSPOT to remotely
 * control a tracked vehicle. This second version attempts to use acceleration
 * tilt along the y-axis to control forward and reverse movement and the
 * embedded switches on the SunSPOT eDemo board to control movement for left
 * and right turns.
 *
 * We experienced difficulty during the user study in controlling left and right
 * turns using acceleration data. The acceleration data is passes rapidly and
 * unwanted conditionals were firing giving some unexpected movements. Using
 * the 2 switches we may be able to isolate turns in either direction to obtain
 * more precise movement. This code is our efforts at using switches.
 */
package org.sunspotworld;

import com.sun.spot.sensorboard.peripheral.IAccelerometer3D;
import com.sun.spot.sensorboard.EDemoBoard;
import com.sun.spot.sensorboard.peripheral.ISwitch;
import com.sun.spot.sensorboard.peripheral.ITriColorLED;
import com.sun.spot.sensorboard.peripheral.LEDColor;

import com.sun.spot.util.Utils;

import java.io.*;

import javax.microedition.io.Connector;
import javax.microedition.io Datagram;
import javax.microedition.io DatagramConnection;
import javax.microedition.midlet.MIDletStateException;

/**
 * The startApp method of this class is called by the VM to start the
 * application.
 *
 * The manifest specifies this class as MIDlet-1, which means it will
 * be selected for execution.
 */
public class RemoteControlVer2 extends javax.microedition.midlet.MIDlet {

    public ISwitch sw1 = EDemoBoard.getInstance().getSwitches()[0];
    public ISwitch sw2 = EDemoBoard.getInstance().getSwitches()[1];
    public ITriColorLED[] leds;
    IAccelerometer3D accel;
    public double LEFT = 150;
    public double RIGHT = -150;

    protected void startApp() throws MIDletStateException {
        System.out.println("Let's control this TrackBot!");
        leds = EDemoBoard.getInstance().getLEDs();
        for (int index = 0; index < 8; index++) {
            leds[index].setOn(); // Initial led test upon SunSPOT turn on
            leds[index].setColor(LEDCOLOR.BLUE); // Set color to BLUE
        }
        accel = EDemoBoard.getInstance().getAccelerometer();
        startSenderThread();
    }

    synchronized public void startSenderThread() {
        new Thread() {
            public void run() {
                // We create a DatagramConnection
                DatagramConnection dgConnection = null;
                Datagram dg = null;
                try {
                    // Open broadcast port 41
                    dgConnection = (DatagramConnection) Connector.open("radiogram://broadcast:41");
                    // Get maximum size datagram
                    dg = dgConnection.newDatagram(dgConnection.getMaximumLength());
                } catch (IOException ex) {
                    System.out.println("Could not open radiogram broadcast connection");
                }
            }
        }.start();
    }
}
```

```

        ex.printStackTrace();
        return;
    }

    while(true){
        try {
            dg.reset();
            if (sw1.isOpen() && sw2.isOpen()){
                dg.writeDouble(accel.getTiltY());
            }
            if (sw1.isClosed()){
                dg.writeDouble(LEFT);
            }
            if (sw2.isClosed()){
                dg.writeDouble(RIGHT);
            }
            dgConnection.send(dg);
            System.out.println("Broadcast is going through");
            System.out.println("We're controlling the TrackBot!!");
        } catch (IOException ex) {
            ex.printStackTrace();
        }
        Utils.sleep(500);
    }
}

}.start();

}

protected void pauseApp() {

}

protected void destroyApp(boolean arg0) throws MIDletStateChangeException {
}
}

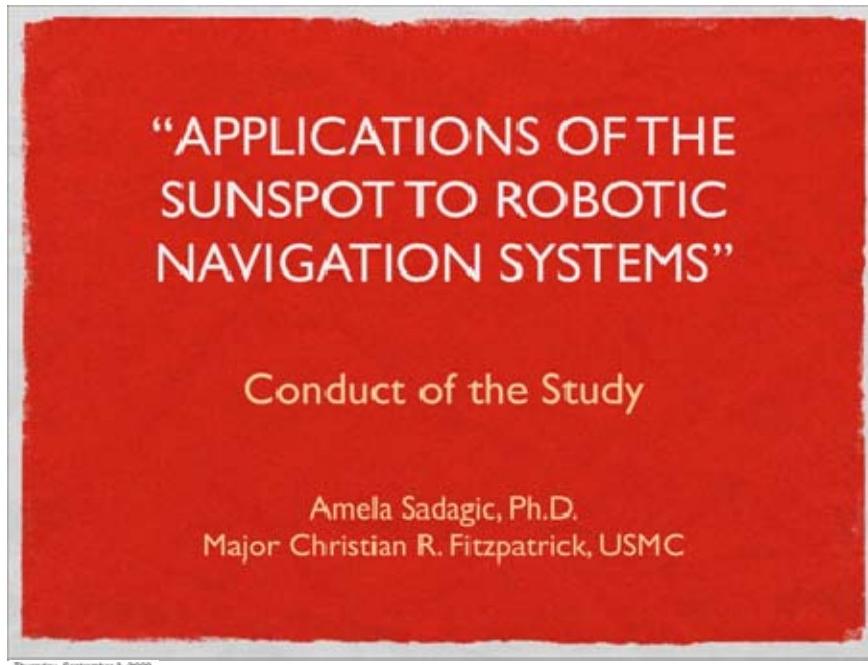
```

APPENDIX B. ROBOTIC CONTROL USER STUDY

A. INTRODUCTION

Appendix B contains all data collected for the control interface evaluation for the NPS Robot. For the study, subjects performed navigation tasks using either the SunSPOT controller or the graphical user interface (GUI) to control the robot. There were three courses used in the study. Once those navigation tasks were complete the subjects were asked to fill out a questionnaire to rate and answer specific questions about the user interface they used for the study. More information about the user study is contained in Chapter III of this thesis.

B. USER STUDY PRESENTATION



INFORMED CONSENT FORM

- **IMPORTANT:** You should have already completed and signed the Informed Consent form.
- If not, please inform Maj Fitzpatrick and this briefing will continue once complete.

Friday, September 4, 2009

CONDUCT OF EXPERIMENT

- Informed Consent form is complete
- Short presentation on the conduct of the study
- Practice period
- Segment #1
- Complete Segment #1 questionnaire
- Segment #2
- Complete Segment #2 questionnaire
- Study complete

Friday, September 4, 2009

SEGMENT #1

- You will use a Graphical User Interface (GUI) to control the small robotic vehicle
- Small Robotic vehicle will start at a designated point
- Press either of the 4 buttons on GUI using a mouse to control movement through each of three courses
- Your task is to successfully drive a small robotic vehicle in a manner described to you

Friday, September 4, 2009

BUTTONS USED TO DRIVE VEHICLES

Stop/Stationary (No button pressed)	
Move Forward	
Move Reverse	
Turn Left	
Turn Right	

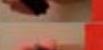
Friday, September 4, 2009

SEGMENT #2

- You will use the SunSPOT device
- Small Robotic vehicle will start at a designated point
- You will rotate the SunSPOT device to control movement through each of three courses
- Your task is to successfully drive a small robotic vehicle in a manner described to you

Friday, September 4, 2009

SUNSPOT DEVICE ROTATION TO DRIVE VEHICLE

Movement	Side View	Front View
Stop/Stationary		
Move Forward		
Move Reverse		
Turn Left		
Turn Right		

Friday, September 4, 2009

COURSES FOR THIS STUDY

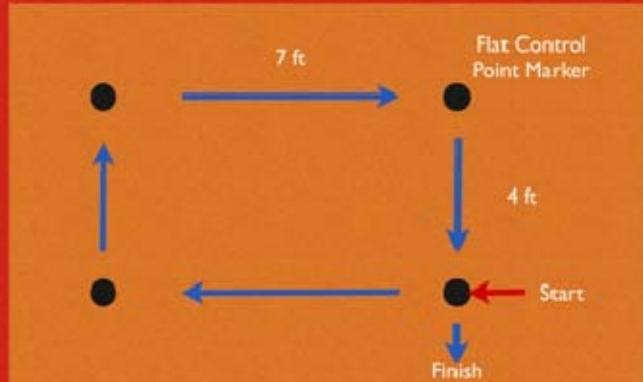
Friday, September 4, 2009

PRACTICE COURSE



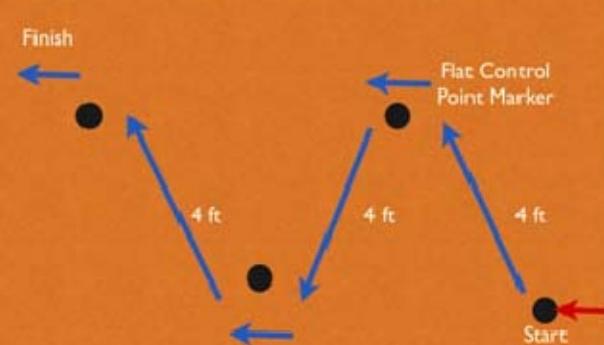
Friday, September 4, 2009

COURSE #1: BOX PATTERN



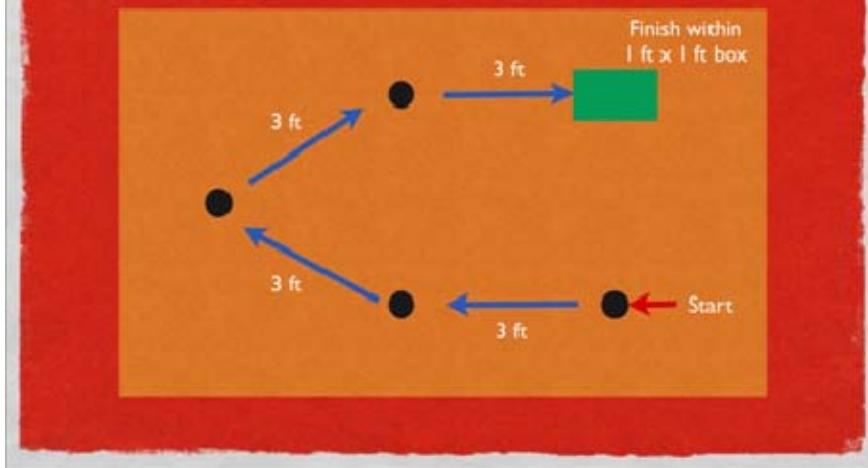
Friday, September 4, 2009

COURSE #2: BOUY AVOIDANCE



Friday, September 4, 2009

COURSE #3: DOCKING ON THE PIER



Friday, September 4, 2009

C. SUNSPOT USER INTERFACE QUESTIONNAIRE

“Applications of SunSPOTS to Create Robotic Navigation Systems”

SunSPOT Interface (GUI) Questionnaire

Thank you for your participation in this study. Please answer the following questions:

1. Please rate the extent to which you were able to control the small robotic vehicle while using the SunSPOT device in each of the three maneuvers. Please circle only one number for each selection.

a) Maneuver #1: Box Pattern

No Control	→	→	→	Full Control
1	2	3	4	5

b) Maneuver #2: Buoy Avoidance

No Control	→	→	→	Full Control
1	2	3	4	5

c) Maneuver #3: Docking at the Pier

No Control	→	→	→	Full Control
1	2	3	4	5

2. Please rate the SunSPOT device on accuracy of control, intuitiveness, and level of strain during use. Please circle only one number for each selection.

a)

Different	→	→	→	Exactly the Same
1	2	3	4	5

b)

Hard to learn	→	→	→	Intuitive
1	2	3	4	5

c)

No Strain/Fatigue	→	→	→	High Strain/Fatigue
1	2	3	4	5

3. Please rate the level of difficulty in completing each maneuver while using the SunSPOT. Please circle only one number for each selection.

a) Maneuver #1: Box Pattern

Difficult	→	→	→	Easy
1	2	3	4	5

b) Maneuver #2: Buoy Avoidance

Difficult	→	→	→	Easy
1	2	3	4	5

c) Maneuver #3: Docking at the Pier

Difficult	→	→	→	Easy
1	2	3	4	5

Have you completed both segments of our study?

NO: *** STOP HERE ***

YES – Go to the next page.

- 4.** If you have completed both conditions of the study, which user input device would you prefer if given the task to control these robotic vehicles for a maritime training display? Please circle one:

SUNSPOT	GUI
---------	-----

Briefly explain:

I liked it because: _____

Any additional comment: _____

- 5.** If you have not already done so, please answer the following questions below.

a) Enter your age (full years): _____

b) Circle your gender:

MALE	FEMALE
------	--------

c) What hand do you use to operate a computer mouse? Please circle one:

LEFT	RIGHT	I am good with either
------	-------	-----------------------

d) Please circle the one selection below that best describes how often do you use web-based menus where selections look like buttons, similar to those found on Amazon and eBay?
Please circle one:

DAILY	WEEKLY	MONTHLY	INFREQUENTLY
-------	--------	---------	--------------

e) Please circle the one selection that best describes your highest level of education attained:

High School/GED	AA/AS	BA/BS	MA/MS	Ph.D
-----------------	-------	-------	-------	------

Reminder—All answers will be treated entirely confidentially. Thank you once again for participating in this study.

NOTE: Please do not discuss it with anyone for at least a week—the study is continuing and others you may happen to speak with may be taking part in this same study as well.

D. GRAPHICAL USER INTERFACE QUESTIONNAIRE

“Applications of SunSPOTs to Create Robotic Navigation Systems”

Graphical User Interface (GUI) Questionnaire

Thank you for your participation in this study. Please answer the following questions:

1. Please rate the extent to which you were able to control the small robotic vehicle while using the GUI in each of the three maneuvers. Please circle only one number for each selection.

a) Maneuver #1: Box Pattern

No Control	→	→	→	Full Control
1	2	3	4	5

b) Maneuver #2: Buoy Avoidance

No Control	→	→	→	Full Control
1	2	3	4	5

c) Maneuver #3: Docking at the Pier

No Control	→	→	→	Full Control
1	2	3	4	5

2. Please rate the GUI on accuracy of control, intuitiveness, and level of strain during use. Please circle only one number for each selection.

a)

Different	→	→	→	Exactly the Same
1	2	3	4	5

b)

Hard to learn	→	→	→	Intuitive
1	2	3	4	5

c)

No Strain/Fatigue	→	→	→	High Strain/Fatigue
1	2	3	4	5

3. Please rate the level of difficulty in completing each maneuver while using the GUI. Please circle only one number for each selection.

a) Maneuver #1: Box Pattern

Difficult	→	→	→	Easy
1	2	3	4	5

b) Maneuver #2: Buoy Avoidance

Difficult	→	→	→	Easy
1	2	3	4	5

c) Maneuver #3: Docking at the Pier

Difficult	→	→	→	Easy
1	2	3	4	5

Have you completed both segments of our study?

NO: *** STOP HERE ***

YES – Go to the next page.

4. If you have completed both conditions of the study, which user input device would you prefer if given the task to control these robotic vehicles for a maritime training display? Please circle one:

SUNSPOT	GUI
---------	-----

Briefly explain:

I liked it because: _____

Any additional comment: _____

5. If you have not already done so, please answer the following questions below.

a) Enter your age (full years): _____

b) Circle your gender:

MALE	FEMALE
------	--------

c) What hand do you use to operate a computer mouse? Please circle one:

LEFT	RIGHT	I am good with either
------	-------	-----------------------

d) Please circle the one selection below that best describes how often do you use web-based menus where selections look like buttons, similar to those found on Amazon and eBay?

Please circle one:

DAILY	WEEKLY	MONTHLY	INFREQUENTLY
-------	--------	---------	--------------

e) Please circle the one selection that best describes your highest level of education attained:

High School/GED	AA/AS	BA/BS	MA/MS	Ph.D
-----------------	-------	-------	-------	------

Reminder—All answers will be treated entirely confidentially. Thank you once again for participating in this study.

NOTE: Please do not discuss it with anyone for at least a week—the study is continuing and others you may happen to speak with may be taking part in this same study as well.

E. COMPILED SUBJECT COMMENTS FROM QUESTIONNAIRES

1. User Study SunSPOT Comments

- X-axis turns were inverted. There were delays in the control interface.
- After 15 seconds of use, it was easy to predict vehicle movement. Then the courses were easy to navigate.
- More complex turns were harder to navigate.
- Making turns was easy, but precision stopping was difficult.
- Getting used to how to work it made all the difference.
- Delays make it as though short choppy motions control it better. I felt as if the turns were backwards.
- The third course was the easiest because I had figured out the interface at that point.
- Box pattern was the easiest because of the straightaways and 90-degree turns.
- Buoy avoidance was the hardest due to the curves.
- Forward and backward worked well, but the turns were opposite.
- Overall, I felt that if the turns were corrected, the SunSPOT would have been much more effective and accurate. Time lag caused some difficulties, but if the vehicle was moved with short movements it worked a lot better.
- Controls became easier with more practice. Once I got used to the inverted controls, maneuvers were accomplished quicker and more accurately. Quick movements with the SunSPOT produced a better outcome than steady movements. In the first 2 trials, the vehicle would continue its movement much after returning to neutral position.
- I felt most comfortable with docking on the pier, because I had become accustomed to the control.
- Tried turning left, but would turn right instead.

- Backward motions travel straight, forward motions seem to guide a little to the left and right.
- Right wheel was weak, constant right turn.
- No left turn capability.
- Only right turn.

2. User Study GUI Comments

- Comments on GUI from User Study:
- Direction of motion more accurate, pauses allow for smooth transition and change in direction.
- Noticed that it worked better as a RWD machine. There is a difference in the lengths of the axles. Measure the voltage to check the power to the wheels. Also, be sure to check the weight distribution. Overall, it is an excellent concept.
- Need to be able to control how far it runs. Try to test on a better surface. It works better as a RWD.
- Vehicle seemed to operate better in reverse. This is possibly due to pushing against the roller vice pulling it from the rear. Needs better voltage regulation. Tires need better traction for this testing surface. The turn procedure is too long. Sometimes turns were a full 180 degrees, vice 90 or 45 degrees.

F. QUANTITATIVE DATA COLLECTED DURING USER STUDY

1. Graphical User Interface (GUI) Responses

Subject Number	GUI Level of Control	GUI Intuitiveness	GUI Level of Difficulty
1	3	4	4
2	2	3	3
3	3	5	2
4	4	5	4
5	3	5	4
6	2	3	3
7	3	4	3
8	4	5	4
9	4	4	4
10	2	5	3
11	3	5	2
12	3	3	4

2. SunSPOT Responses

Subject Number	SunSPOT Level of Control	SunSPOT Intuitiveness	SunSPOT Level of Difficulty
13	2.5	2	3.33
14	3	4	3
15	2	4	2
16	3	4	3
17	3.5	3	3
18	2	4	2.67
19	2	3	3
20	2	3	2

21	2.75	3	2
22	3.25	3	2.67
23	3.25	3	3
24	3	4	3.33

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APPENDIX C. X3D ANIMATIONS

A. INTRODUCTION

Appendix C contains source code for example animations created in X3D for use in the modernized EWD. This code can be used as a template for the development of additional animations. Three animations are scenes showing notional enemy activity at MCB Camp Pendleton. The fourth animation is a depiction of a UAV collecting intelligence over NAB Coronado. These animations are available for download in the Savage Defense model archive.

B. EWD ANIMATION #1: WEAPONS DROP

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE X3D PUBLIC "ISO//Web3D//DTD X3D 3.2//EN"
"http://www.web3d.org/specifications/x3d-3.2.dtd">
<X3D profile='Immersive' version='3.2' xmlns:xsd='http://www.w3.org/2001/XMLSchema-instance' xsd:noNamespaceSchemaLocation='http://www.web3d.org/specifications/x3d-3.2.xsd'>
  <head>
    <meta content='EWDSceen1.x3d here' name='title'/>
    <meta content='Suspected weapons drop to insurgents via cargo transport aircraft' name='description'/>
    <meta content='Christian Fitzpatrick' name='creator'/>
    <meta content='21 July 09' name='created'/>
    <component level='2' name='Geospatial'/>
  </head>
  <Scene>
    <GeoViewpoint description='GeoViewpoint_0_00' geoSystem='"GDC"' orientation='0 1 0 1.57' position='33.309032985248216 -117.32484464090435 27515.113914969108'>
      <GeoOrigin DEF='ORIGIN' geoCoords='33.309032985248216 -117.32484464090435 0' geoSystem='GDC' />
    </GeoViewpoint>
    <Inline DEF='K2' url='../../../../X3DEarth/NGA/K2/tiles/0/k20-0.x3d' />
    <Group DEF='CargoDrop'>
      <GeoLocation DEF='CargoTransport' geoCoords='33.316709 -117.343846 150'>
        <GeoOrigin USE='ORIGIN' />
        <Transform DEF='CargoTransportRotation' rotation='0 1 0 0' scale='5 5 5'>
          <GeoTouchSensor DEF='CargoTransportTouched' description='touch to activate' geoSystem='GDC' />
          <Inline url='../../../../Desktop/CESSNA 525/GEOMETRY/CESSNA 525_Genair.x3d' />
        </Transform>
        <TimeSensor DEF='MasterTime' cycleInterval='32' loop='true' />
        <TimeSensor DEF='RotationInterval' cycleInterval='2' enabled='true' loop='true' />
        <OrientationInterpolator DEF='CargoTransportTurn' key='0 0.143 0.286 0.429 0.571 0.714 0.857 1' keyValue='0 1 0 3.75 0 1 0 3.75 0 1 0 3.75 0 1 0 2.355 0 1 0 2.355 0 1 0 3.75 0 1 0 3.75 0 1 0 5.2' />
        <GeoPositionInterpolator DEF='CargoTransportInbound' key='0 0.143 0.286 0.429 0.571 0.714 0.857 1' keyValue='33.316708 -117.343849 150 33.306709 -117.361847 40 33.296871 -117.379059 30 33.296852 -117.379059 30 33.297855 -117.380951 40 33.297855 -117.380959 40 33.295876 -117.384758 40 33.295853 -117.384758 45' />
        <TimeTrigger DEF='Filter' />
        <ROUTE fromField='isActive' fromNode='CargoTransportTouched' toField='set_boolean' toNode='Filter' />
        <ROUTE fromField='triggerTime' fromNode='Filter' toField='startTime' toNode='MasterTime' />
        <ROUTE fromField='triggerTime' fromNode='Filter' toField='startTime' toNode='RotationInterval' />
        <ROUTE fromField='fraction_changed' fromNode='MasterTime' toField='set_fraction' toNode='CargoTransportTurn' />
        <ROUTE fromField='value_changed' fromNode='CargoTransportTurn' toField='set_value' toNode='CargoTransportTouched' />
    </Group>
  </Scene>
</X3D>
```

```

        toField='set_rotation' toNode='CargoTransportRotation' />
    <ROUTE fromField='fraction_changed' fromNode='MasterTime' toField='set_fraction'
          toNode='CargoTransportInbound' />
    <ROUTE fromField='geovalue_changed' fromNode='CargoTransportInbound'
          toField='geoCoords' toNode='CargoTransport' />
    <TimeTrigger />
</GeoLocation>
</Group>
<Group DEF='InsurgentTruck1'>
    <GeoLocation DEF='TruckLoc' geoCoords='33.295853 -117.387561 90'>
        <GeoOrigin USE='ORIGIN' />
        <Transform rotation='0 1 0 0.6' scale='10 10 10'>
            <Inline url='../../../../Desktop/NissanRover/NissanRoverGreen.x3d' />
        </Transform>
    </GeoLocation>
</Group>
</Scene>
</X3D>

```

C. EWD ANIMATION #2: VEHICLE DEPARTURE

```

<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE X3D PUBLIC "ISO//Web3D//DTD X3D 3.2//EN"
"http://www.web3d.org/specifications/x3d-3.2.dtd">
<X3D profile='Immersive' version='3.2'
xmlns:xsd='http://www.w3.org/2001/XMLSchema-instance'
xsd:noNamespaceSchemaLocation='http://www.web3d.org/specifications/x3d-3.2.xsd'>
    <head>
        <meta content='EWDScape2.x3d here' name='title' />
        <meta content='Cargo transport aircraft departure after weapons drop'
              name='description' />
        <meta content='Christian Fitzpatrick' name='creator' />
        <meta content='21 July 09' name='created' />
        <component level='2' name='Geospatial' />
    </head>
    <Scene>
        <GeoViewpoint description='GeoViewpoint_0_00' geoSystem='"GDC"'
                      orientation='0 1 0 1.57' position='33.309032985248216 -117.32484464090435
                      27515.113914969108' />
        <GeoOrigin DEF='ORIGIN' geoCoords='33.309032985248216 -117.32484464090435
                      0' geoSystem='GDC' />
    </GeoViewpoint>
    <Inline DEF='K2' url='../../../../X3DEarth/NGA/K2/tiles/0/k20-0.x3d' />
    <Group DEF='CargoDrop'>
        <GeoLocation DEF='CargoTransport' geoCoords='33.294754 -117.383064 40'>
            <GeoOrigin USE='ORIGIN' />
            <Transform DEF='CargoTransportRotation' rotation='0 1 0 0.6'
                       scale='5 5 5'>
                <GeoTouchSensor DEF='CargoTransportTouched'
                                description='touch to activate' geoSystem='GDC' />
                <Inline url='../../../../Desktop/CESSNA 525/GEOMETRY/CESSNA
                            525_Genair.x3d' />
            </Transform>
            <TimeSensor DEF='MasterTime' cycleInterval='20' loop='true' />
            <GeoPositionInterpolator DEF='CargoTransportInbound'
                                      key='0 0.5 1'
                                      keyValue='33.294754 -117.383064 40 33.306709 -117.361847 40
                                      33.316708 -117.343849 250' />
            <TimeTrigger DEF='Filter' />
            <ROUTE fromField='isActive' fromNode='CargoTransportTouched'
                  toField='set_boolean' toNode='Filter' />
            <ROUTE fromField='triggerTime' fromNode='Filter' toField='startTime'
                  toNode='MasterTime' />
            <ROUTE fromField='fraction_changed' fromNode='MasterTime'
                  toField='set_fraction' toNode='CargoTransportInbound' />
            <ROUTE fromField='geovalue_changed' fromNode='CargoTransportInbound'
                  toField='geoCoords' toNode='CargoTransport' />
            <TimeTrigger />
        </GeoLocation>
    </Group>

```

```

    </Group>
  </Scene>
</X3D>
```

D. EWD ANIMATION #3: AIRCRAFT DEPARTURE

```

<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE X3D PUBLIC "ISO//Web3D//DTD X3D 3.2//EN"
"http://www.web3d.org/specifications/x3d-3.2.dtd">
<X3D profile='Immersive' version='3.2'
xmlns:xsd='http://www.w3.org/2001/XMLSchema-instance'
xsd:noNamespaceSchemaLocation='http://www.web3d.org/specifications/x3d-3.2.xsd'>
  <head>
    <meta content='EWDScene3.x3d here' name='title'/>
    <meta content='Vehicle get away after weapons drop, enroute K-2'
      name='description'/>
    <meta content='Christian Fitzpatrick' name='creator'/>
    <meta content='21 July 09' name='created'/>
    <component level='2' name='Geospatial'/>
  </head>
  <Scene>
    <GeoViewpoint description='GeoViewpoint_0_00' geoSystem='GDC'!
      orientation='0 1 0 1.57' position='33.309032985248216 -117.32484464090435
      27515.113914969108'>
      <GeoOrigin DEF='ORIGIN' geoCoords='33.309032985248216 -117.32484464090435
      0' geoSystem='GDC'!/>
    </GeoViewpoint>
    <Inline DEF='K2' url='../../../../X3DEarth/NGA/K2/tiles/0/k20-0.x3d'!/>
    <Group DEF='NissanEscape'>
      <GeoLocation DEF='Nissan' geoCoords='33.290955 -117.383759 40'>
        <GeoOrigin USE='ORIGIN'>
          <Transform DEF='NissanRotation' rotation='0 1 0 0' scale='5 5 5'>
            <GeoTouchSensor DEF='NissanTouched' description='touch to activate'
              geoSystem='GDC'!/>
            <Inline url='../../../../Desktop/NissanRover/NissanRoverGreen.x3d'!/>
          </Transform>
          <TimeSensor DEF='MasterTime' cycleInterval='32' loop='true'!/>
          <TimeSensor DEF='RotationInterval' cycleInterval='2'
            enabled='true' loop='true'!/>
          <OrientationInterpolator DEF='NissanTurn'
            key='0 0.143 0.286 0.429 0.571 0.714 0.857 1'
            keyValue='0 1 0 0.5 0 1 0 0.5 0 1 0 0.7 0 1 0 0.7 0 1 0 2.355 0 1
            0 2.355 0 1 0 2.355 0 1 0 2.355'!/>
          <GeoPositionInterpolator DEF='NissanDrive'
            key='0 0.143 0.286 0.429 0.571 0.714 0.857 1'
            keyValue='33.290955 -117.383759 40 33.298508 -117.361046 40
            33.301708 -117.35685 40 33.306408 -117.351349 40 33.307407 -
            117.353348 40 33.318008 -117.364044 80 33.323009 -117.366043 120
            33.324509 -117.368149 140'!/>
          <TimeTrigger DEF='Filter'!/>
          <ROUTE fromField='isActive' fromNode='NissanTouched'
            toField='set_boolean' toNode='Filter'!/>
          <ROUTE fromField='triggerTime' fromNode='Filter' toField='startTime'
            toNode='MasterTime'!/>
          <ROUTE fromField='triggerTime' fromNode='Filter' toField='startTime'
            toNode='RotationInterval'!/>
          <ROUTE fromField='fraction_changed' fromNode='MasterTime'
            toField='set_fraction' toNode='NissanTurn'!/>
          <ROUTE fromField='value_changed' fromNode='NissanTurn'
            toField='set_rotation' toNode='NissanRotation'!/>
          <ROUTE fromField='fraction_changed' fromNode='MasterTime'
            toField='set_fraction' toNode='NissanDrive'!/>
          <ROUTE fromField='geovalue_changed' fromNode='NissanDrive'
            toField='geoCoords' toNode='Nissan'!/>
        <TimeTrigger/>
      </GeoLocation>
```

```

    </Group>
  </Scene>
</X3D>
```

E. EWD ANIMATION #4: GLOBAL HAWK UAV IMAGERY TRANSMISSION

```

<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE X3D PUBLIC "ISO//Web3D//DTD X3D 3.2//EN"
"http://www.web3d.org/specifications/x3d-3.2.dtd">
<X3D profile='Immersive' version='3.2'
xmlns:xsd='http://www.w3.org/2001/XMLSchema-instance'
xsd:noNamespaceSchemaLocation='http://www.web3d.org/specifications/x3d-3.2.xsd'>
  <head>
    <meta content='EWDScene4.x3d here' name='title'/>
    <meta content='Suspected weapons drop to insurgents via cargo transport
      aircraft' name='description'/>
    <meta content='Christian Fitzpatrick' name='creator'/>
    <meta content='21 July 09' name='created'/>
    <component level='2' name='Geospatial'/>
  </head>
  <Scene>
    <GeoViewpoint description='GeoViewpoint_0_00' geoSystem='"GDC"'
      orientation='0 1 0 1.57' position='33.309032985248216 -117.32484464090435
      27515.113914969108'>
      <GeoOrigin DEF='ORIGIN' geoCoords='33.309032985248216 -117.32484464090435
      0' geoSystem='GDC' />
    </GeoViewpoint>
    <Inline DEF='K2' url='../../../../X3DEarth/NGA/K2/tiles/0/k20-0.x3d' />
    <Group DEF='NissanEscape'>
      <GeoLocation DEF='Nissan' geoCoords='33.290955 -117.383759 40'>
        <GeoOrigin USE='ORIGIN' />
        <Transform DEF='NissanRotation' rotation='0 1 0 0' scale='5 5 5'>
          <GeoTouchSensor DEF='NissanTouched' description='touch to activate
            geoSystem="GDC"' />
          <Inline url='../../../../Desktop/NissanRover/NissanRoverGreen.x3d' />
        </Transform>
        <TimeSensor DEF='MasterTime' cycleInterval='32' loop='true' />
        <TimeSensor DEF='RotationInterval' cycleInterval='2' enabled='true'
          loop='true' />
        <OrientationInterpolator DEF='NissanTurn'
          key='0 0.143 0.286 0.429 0.571 0.714 0.857 1'
          keyValue='0 1 0 2.355 0 1 0 2.355 0 1 0 2.355 0 1 0
          2.355 0 1 0 2.355 0 1 0 2.355 0 1 0 2.355' />
        <GeoPositionInterpolator DEF='NissanDrive'
          key='0 0.143 0.286 0.429 0.571 0.714 0.857 1'
          keyValue='33.32951 -117.369843 140 33.334007 -117.373848 140
          33.340008 -117.372345 140 33.34201 -117.372345 140 33.347111 -
          117.375443 140 33.346409 -117.372749 140 33.346409 -117.369743 140
          33.345409 -117.368744 140' />
        <TimeTrigger DEF='Filter' />
        <ROUTE fromField='isActive' fromNode='NissanTouched'
          toField='set boolean' toNode='Filter' />
        <ROUTE fromField='triggerTime' fromNode='Filter' toField='startTime'
          toNode='MasterTime' />
        <ROUTE fromField='triggerTime' fromNode='Filter' toField='startTime'
          toNode='RotationInterval' />
        <ROUTE fromField='fraction_changed' fromNode='MasterTime'
          toField='set_fraction' toNode='NissanTurn' />
        <ROUTE fromField='value_changed' fromNode='NissanTurn'
          toField='set_rotation' toNode='NissanRotation' />
        <ROUTE fromField='fraction_changed' fromNode='MasterTime'
          toField='set_fraction' toNode='NissanDrive' />
        <ROUTE fromField='geovalue_changed' fromNode='NissanDrive'
          toField='geoCoords' toNode='Nissan' />
    </Group>
  </Scene>
</X3D>
```

```
<TimeTrigger/>
</GeoLocation>
</Group>
</Scene>
</X3D>
```

F. SAVAGE DEFENSE WEBLINKS TO EWD ANIMATIONS

<https://SavageDefense.nps.navy.mil/SavageDefense/EWDAnimations/EWDAnimation1/EWDAnimation1.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/EWDAnimations/EWDAnimation2/EWDAnimation2.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/EWDAnimations/EWDAnimation3/EWDAnimation3.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/EWDAnimations/EWDAnimation4/EWDAnimation4.x3d>

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APPENDIX D. PROCESSING INPUT MOVIE FILES FOR MULTIPROJECTOR DISPLAY

A. INTRODUCTION

This appendix shows source code used to process movie files of X3D scenes for projection in the modernized EWD. This code was developed using the Computer Vision (OpenCV) libraries and can accommodate a four-projector setup. The code can be expanded to add additional projectors. Written using Xcode (the Mac OSX development environment), this code takes an input movie file and segments the input into 4 separate videos by defining multiple regions of interest.

B. SOURCE CODE

```
#include <OpenCV/OpenCV.h>

int main (int argc, char** argv) {

    cvNamedWindow("EWDVideoUpperLeft", CV_WINDOW_AUTOSIZE);
    cvNamedWindow("EWDVideoUpperRight", CV_WINDOW_AUTOSIZE);
    cvNamedWindow("EWDVideoLowerLeft", CV_WINDOW_AUTOSIZE);
    cvNamedWindow("EWDVideoLowerRight", CV_WINDOW_AUTOSIZE);

    const char* movieFile =
        "/Users//christianfitzpatrick//OpenCV//splitScreen//movieFile.mov";

    CvCapture* capture = cvCreateFileCapture(movieFile);

    IplImage* frameUL;
    IplImage* frameUR;
    IplImage* frameLL;
    IplImage* frameLR;

    while (1) {

        frameUL = cvQueryFrame(capture);
        frameUR = cvQueryFrame(capture);
        frameLL = cvQueryFrame(capture);
        frameLR = cvQueryFrame(capture);

        if (!frameUL || !frameUR || !frameLL || !frameLR) {
            printf("No Frame Available");
            break;
        }

        // Upper Left
        CvRect rectUL = cvRect(0, 0, cvRound((frameUL->width - 1) / 2),
                               cvRound((frameUL->height - 1) / 2));
        cvSetImageROI(frameUL, rectUL);
        cvShowImage("EWDVideoUpperLeft", frameUL);
        cvResetImageROI(frameUL);

        // Upper Right
        CvRect rectUR = cvRect(cvRound((frameUR->width - 1) / 2), 0,
                               cvRound((frameUR->width - 1) / 2), cvRound((frameUR->height - 1) / 2));
    }
}
```

```

cvSetImageROI(frameUR, rectUR);
cvShowImage("EWDVideoUpperRight", frameUR);
cvResetImageROI(frameUR);

// Lower Left
CvRect rectLL = cvRect(0, cvRound((frameLL->height - 1) / 2),
                      cvRound((frameLL->width - 1) / 2),
                      cvRound((frameLL->height - 1) / 2));
cvSetImageROI(frameLL, rectLL);
cvShowImage("EWDVideoLowerLeft", frameLL);
cvResetImageROI(frameLL);

// Lower Right
CvRect rectLR = cvRect(cvRound((frameLR->width - 1) / 2,
                               cvRound((frameLR->height - 1) / 2),
                               cvRound((frameLR->width - 1) / 2),
                               cvRound((frameLR->height - 1) / 2));
cvSetImageROI(frameLR, rectLR);
cvShowImage("EWDVideoLowerRight", frameLR);
cvResetImageROI(frameLR);

char c = cvWaitKey(33);
if (c == 27) break;
}

cvReleaseCapture (&capture);
cvDestroyWindow("EWDVideoUpperLeft");
cvDestroyWindow("EWDVideoUpperRight");
cvDestroyWindow("EWDVideoLowerLeft");
cvDestroyWindow("EWDVideoLowerRight");
}

```

APPENDIX E. EWD MODEL INVENTORIES

A. INTRODUCTION

Appendix E contains three tables containing model data for the EWD. The first table contains a listing of all models displayed in the current configuration of the EWD. The second table is a listing of the models recommended for a modernized EWD. The third table is a listing of 3D models available for X3D scenes for use in tactical training scenarios. Finally, a listing of the Savage Defense model archive weblinks to all models used in this thesis is presented.

B. CURRENT SHIP COMPOSITION FOR EWD

Type	Nomenclature	Number	Notes
Aircraft Carrier	CVN/CV	8	
Amphibious Assault Ship	LHA/LHD	5	5 LHA for MEB
Destroyers	DDG	12	
Landing Ship Dock	LSD	7	
Landing Ship, Tank	LST	10	No longer in service
Amphibious Cargo Ship	LKA	8	No longer in service
Amphibious Transport Ship	LPA	6	No longer in service
High-speed Transport	APD	7	No longer in service
Landing Craft Vehicle and Personnel	LCVP	4 waves	Replace with LCU/LCAC

C. PROPOSED SHIP COMPOSITION FOR EWD MODERNIZATION

Type	Nomenclature	Number	Notes
Aircraft Carrier	CVN/CV	2	2 CSGs
Amphibious Assault Ship	LHA/LHD	5	5 ESGs (1 MEB)
Destroyers	DDG	9	1 per ESG, 2 per CSG
Landing Ship, Dock	LSD	7	1 per ESG, 1 per CSG
Amphibious Transport Dock	LPD	7	1 per ESG, 1 per CSG
Guided Missile Cruiser	CG	9	1 per ESG, 2 per CSG
Frigate	FFG	5	1 per ESG

Supply Ship	AOE/AOR	2	1 per CSG
Landing Craft Air Cushioned	LCAC	10 (5 waves)	2 per ESG, 2 controlled by 1 SunSPOT
Landing Craft Utility	LCU	15 (5 waves)	3 per ESG, 3 controlled by 1 SunSPOT
Total SunSPOTs Required		56	

D. X3D MODELS REQUIRED FOR EWD MODERNIZATION

Type	Nomenclature	Number	Notes
CH-46E Sea Knight	CH-46E	12	Expect to be replaced by MV-22
CH-53E	CH-53E	3	
AH-1W Cobra	AH-1W	4	Expected to be replaced by AH-1Z
UH-1N Huey	UH-1N	3	Expected to be replaced by UH-1Y
AV-8B Harrier	AV-8B	6	
KC-130J Hercules	KC-130J	2	
MV-22 Osprey	MV-22	12	Replace the CH-46
F-35 Joint Strike Fighter	F-35	6	Replace AV-8B
M1A1 Main Battle Tank	M1A1	4	
Light Armored Vehicle		16	
Amphibious Assault Vehicle	AAV	15	Expect to be replaced by EFV
155mm Howitzer (M198)	M198	6	
M252 81mm Mortar Tube	M252	8	
BGM-71 TOW Missile Weapon System	BGM-71	8	
FGM-148 Javelin Anti-Tank Missile	FGM-148	8	
Tomahawk Land Attack Missile	TLAM	1	
Expeditionary Fighting Vehicle	EFV	15	Replace the AAV
Medium Tactical Vehicle Replacement	MTVR	30	"7 Ton"
High Mobility Multi-purpose Wheeled Vehicle	HMMWV	63	
Ballistic Missile Submarine	SSBN	1	

E. SAVAGE DEFENSE WEBLINKS TO ALL MODIFIED AMEX MODELS

1. Fixed Wing Aircraft

<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftFixedWing/A10Thunderbolt/A10Thunderbolt.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftFixedWing/AV8BHarrier/AV8BHarrier.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftFixedWing/B2Spirit/B2Spirit.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftFixedWing/C130Hercules/C130Hercules.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftFixedWing/E2CHawkeye/E2CHawkeye.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftFixedWing/E2CHawkeye/COD.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftFixedWing/F15Eagle/F15Eagle.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftFixedWing/F16Falcon/F16Falcon.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftFixedWing/F22ARaptor/F22ARaptor.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftFixedWing/FA18Hornet/FA18EFHornet.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftFixedWing/KC10AExtender/KC10AExtender.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftFixedWing/T38Talon/T3812th.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftFixedWing/T38Talon/T38ASC.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftFixedWing/T38Talon/T38Agressor.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftFixedWing/U2TR1/U2TR1.x3d>

2. Helicopters

<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftHelicopters/AH1WSuperCobra/AH1WSuperCobra.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftHelicopters/CH46SeaKnight/CH46SeaKnight.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftHelicopters/CH53ESeaStallion/CH53ESeaStallion.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftHelicopters/UH1NIroquois/UN1NHuey.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftHelicopters/UH60BlackHawk/UH60BlackHawk.x3d>

3. Miscellaneous Aircraft

<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftMiscellaneous/GPSSatellite/GPSSatellite.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftMiscellaneous/RAVEN/Raven.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftMiscellaneous/RQ1Predator/RQ1Predator.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/AircraftMiscellaneous/RQ4GlobalHawk/RQ4GlobalHawk.x3d>

4. Avatars

<https://SavageDefense.nps.navy.mil/SavageDefense/Avatars/animatedPlatoonBlue/animatedPlatoonBlue.x3d>
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5. Buildings

<https://SavageDefense.nps.navy.mil/SavageDefense/Buildings/MetalBuilding/MetalBuilding.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/Buildings/MilitaryAirfield/MilitaryAirfield.x3d>

6. Ground Vehicles

<https://SavageDefense.nps.navy.mil/SavageDefense/GroundVehicles/Jeep/JeepGray.x3d>
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<https://SavageDefense.nps.navy.mil/SavageDefense/GroundVehicles/TruckTankTransporter/TruckTankTransporterTan.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/GroundVehicles/VERSALIFT/VERSALIFTYellow.x3d>

7. Naval Vessels

<https://SavageDefense.nps.navy.mil/SavageDefense/ShipsMilitary/AAV/AAV.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/ShipsMilitary/AOE1Sacramento/AOE1Sacramento.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/ShipsMilitary/CG52BunkerHill/CG52BunkerHill.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/ShipsMilitary/CVN68Nimitz/CVN68Nimitz.x3d>
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<https://SavageDefense.nps.navy.mil/SavageDefense/ShipsMilitary/DDG51ArleighBurke/DDG51ArleighBurke.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/ShipsMilitary/EFV/EFV.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/ShipsMilitary/FF1094Pharris/FF1094Pharris.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/ShipsMilitary/LCAC/LCAC.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/ShipsMilitary/LCC19BlueRidge/LCC19BlueRidge.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/ShipsMilitary/LCU/LCU.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/ShipsMilitary/LHA1Tarawa/LHA1Tarawa.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/ShipsMilitary/LPD4Austin/LPD4Austin.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/ShipsMilitary/LSD41WhidbeyIsland/LSD41WhidbeyIsland.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/ShipsMilitary/LSD48Ashland/LSD48Ashland.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/ShipsMilitary/PTBoat/PTBoat.x3d>
<https://SavageDefense.nps.navy.mil/SavageDefense/ShipsMilitary/SSN688LosAngeles/SSN688LosAngeles.x3d>

8. Weapons

<https://SavageDefense.nps.navy.mil/SavageDefense/Weapons/AK47AssaultRifle/AK47StandardAssaultRifle.x3d>

<https://SavageDefense.nps.navy.mil/SavageDefense/Weapons/AK47AssaultRifle/AK47GrayAssaultRifle.x3d>

<https://SavageDefense.nps.navy.mil/SavageDefense/Weapons/M9Barreta/M9Barreta.x3d>

<https://SavageDefense.nps.navy.mil/SavageDefense/Weapons/SA7Grail/SA7Grail.x3d>

<https://SavageDefense.nps.navy.mil/SavageDefense/Weapons/SA14Gremlin/SA14Gremlin.x3d>

<https://SavageDefense.nps.navy.mil/SavageDefense/Weapons/SA16Gimlet/SA16Gimlet.x3d>

APPENDIX F. EWD HISTORICAL DOCUMENTS AND PHOTOS

A. INTRODUCTION

This appendix contains historical data collected from the EWD by the EWTGLANT staff and provided to NPS for this research. The data includes early photos and information pamphlets presented to observers. Notes from the initial EWD Planning Conference held on 2 August 1951 are provided as well. Those documents are marked CONFIDENTIAL. Department of Defense 5200.1-R Information Security Program paragraph C4.3.1.1 states “Executive Order 12958 established a system for declassification of information in permanently valuable historical records 25 years from the date of original classification” (Department of Defense, 1997). In accordance with this reference, EWTGLANT Security Manager released these documents for this thesis work as they are now UNCLASSIFIED. In addition, two blueprints used for construction of the X3D model of the facility are presented. The actual blueprints were produced by The Austin Company from New York, N.Y. The first floor plan blueprint was produced on March 26, 1957, and the catwalk blueprint was produced on October 1, 1956.

B. EARLY PHOTO OF SAILOR WORKING IN PROJECTION ROOM



Figure 60. Early Photo of EWD Projection Room on Second Deck (Date Unknown)

C. EARLY EWD PAMPHLET (DATE UNKNOWN)



AMPHIBIOUS TRAINING DEMONSTRATOR

Welcome to the Amphibious Training Demonstrator. Before you is a unique training device which presents a complete amphibious assault from the initial advance force operations to the post-landing operations on the beach, utilizing ships, planes, movies, slides, and special audio effects.

The Amphibious Training Demonstrator was built by the Austin Company in the mid-50s to instruct and train personnel of the Navy, Army, and Marine Corps in the doctrines, tactics, and techniques of all phases of an amphibious operation. The facilities used for the operation of this device are extensive and include a projection system with both movies and slides, three separate speaker systems, tape recorders, special sound effects, and special lighting effects.

The demonstration floor measures 96 feet by 69 feet with one-third of the floor area taken up by the simulated terrain of Orange Island. The remaining two-thirds represents the sea area off the coast. The terrain is constructed of specially laminated mahogany which has been painted to represent actual terrain features and can be modified with items such as wood, burlap, and clay to represent an actual coastline anywhere in the world.

The special lighting effects can be utilized to simulate any portion of a day from midnight to sunrise or sunset. By the use of special spotlights in the overhead, single objects may be emphasized. The demonstration floor can be flooded with ultra-violet light to cause the specially painted items on the floor to stand out.

An electronic device simulates shore bombardment of the beach from the gunfire support ships stationed off the coast. When a ship fires, a flash of light and a puff of smoke is emitted with a report of an explosion or shell burst on the terrain. Delay is incorporated to represent the time of flight of the projectile, allowing you, the viewer, to watch both the firing and the resulting explosion on the land. Several of the targets are constructed to collapse when hit by this gunfire.

The Amphibious Training Demonstrator is but one of the many special and elaborate training devices used by the U. S. Navy to enhance and develop the skills of personnel concerned with amphibious operations. The models used in this presentation are constantly updated by Mr. Louis THEISZ of the Training Support Department of the Naval Amphibious School Little Creek.

D. INITIAL AUGUST 1951 EWD CONFERENCE NOTES (DECLASSIFIED)

NAVAL AMPHIBIOUS TRAINING UNIT
U.S. NAVAL AMPHIBIOUS BASE
LITTLE CREEK, NORFOLK, VIRGINIA

6
TU/A3
Serial 0116
4 August 1951

~~CONFIDENTIAL~~

From: Commanding Officer
To: Commander Amphibious Force, U.S. Atlantic Fleet
Commander Amphibious Group TWO, U.S. Atlantic Fleet
Commander Amphibious Group FOUR, U.S. Atlantic Fleet
Commander Transport Division 24, U.S. Atlantic Fleet
Commander Amphibious Training Command, U.S. Atlantic Fleet
Commanding General, Troop Training Unit, U.S. Atlantic Fleet
Subj: Amphibious Assault Teacher and Evaluator Conference notes,
forwarding of
Ref: (a) CG NATU coaf spdltr 0113 dtd 31 July 1951
Encl: (1) Subject notes

1. In accordance with reference (a), a conference to discuss preliminary specifications for the Amphibious Assault Teacher and Evaluator to be constructed at the Naval Amphibious Base, Little Creek, Norfolk, Virginia, was held at 1000R, 2 August 1951.
2. Enclosure (1) is forwarded herewith for information.

L. J. MANNES

Copy to:
CG NavPhiBase (Attn. PWOfficer)
O-in-C, LCCS
O-in-C, MEOS
O-in-C, AIRSS
O-in-C, GPS3
Mr. Stevens, Representative of Special Devices Center (2) ←
Army Liaison Officer, ComPhibtralant

AUTHENTICATED:

A. G. Field
A. G. FIELD
LCDR USNR
Administrative Officer

~~CONFIDENTIAL~~

(DECLASSIFIED)

~~CONFIDENTIAL~~
NOTES ON CONFERENCE HELD TO DISCUSS AMPHIBIOUS ASSAULT TEACHER AND
EVALUATOR ON 2 AUGUST 1951

In accordance with announcement contained in Commanding Officer, Naval Amphibious Training Unit confidential speedletter ser 0113 dated 31 July, 1951, a conference of officers representing local Armed Forces commands interested in amphibious operations, and representatives of the Special Devices Center, Office of Naval Research, and the Austin Company, was held at 1000, 2 August 1951, in the Conference Room of Building 3129, U.S. Naval Amphibious Base, Little Creek, Norfolk, Virginia.

The conference was opened by CAPT L. J. MANEES, Commanding Officer, Naval Amphibious Training Unit, who remarked that certain funds had been appropriated for the construction of a permanent Amphibious Assault Teacher and Evaluator on the U.S. Naval Amphibious Base, Little Creek, Norfolk, Virginia. Specifically, \$198,000 has been appropriated for the construction of a building in which to house this device, and between three and four hundred thousand dollars for the device itself. The contract for construction of this device has been awarded to the Austin Company, some of whose representatives were present at the conference.

The general concept of the Teacher was briefly outlined in the letter announcing the conference, CAPT MANEES pointed out, after which he read the salient points for the benefit of those present who had not seen the announcement.

CAPT MANEES called roll, and it was found that the following persons were present:

world
CAPT MANEES, Commanding Officer, Naval Amphibious Training Unit
CAPT WAGNER, Operations Officer, Commander Amphibious Training Command
COL BARTON, USA, Army Liaison Officer, ComPhibTralant - X-47
→ COL FLOOM, USMC, G-4, Troop Training Unit - X 812
CDR ADAMS, Officer-in-Charge, Naval Beach Group School
CDR DEACON, Officer-in-Charge, Air Support School
CDR GUNN, Training Officer, ComPhibTralant
CDR INGLING, Planning Officer, Amphibious Group TWO - X 617
CDR KIRKPATRICK, Officer-in-Charge, Landing Craft Control School
CDR LEWIS, prospective Executive Officer, Naval Amphibious Training Unit
→ CDR LINEHAM, representing Amphibious Group FOUR - Jeannie - N.O.C.
CDR MORGAN, Chief Instructor, Gunfire Support School
→ CDR SCHRIETER, Training & Gunnery Officer, Amphibious Group TWO -
MAJ McHENRY, Staff, ComPhibTralant
LT GEISERT, Training Device Officer, Naval Amphibious Training Unit
LTJC SIMONSON, representing Public Works, Naval Amphibious Base
MR STEVENS, representing Special Devices Center, Office of Naval Research
MR BIRKEL, representing the Austin Company
MR JENNINGS, representing the Austin Company
MR JIRAK, representing the Austin Company.

CAPT MANEES stated that the purpose of the conference was to discuss the proposed device from the standpoint of the various commands which might have occasion to use it, and to insure that it will be as complete and flexible as possible within financial limitations. He expressed the

~~CONFIDENTIAL~~

(1) - 1

ENCLOSURE (1) to
CO NATU conf ltr 0116
dtd 4 August 1951

(DECLASSIFIED)

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hope that the Teacher would be as useful as the Supporting Arms Evaluator. He urged representatives of the commands present to express ideas as to what should be included in this device. CAPT MANEES called upon LTJG SIMONSON to outline briefly the plans for the building in which the device will be installed.

LTJG SIMONSON described the projected building as of concrete block construction. Its dimensions are to be 142' x 102', with actual operating area of 70' x 100'. On both sides of the operating area, there are to be platforms for seats for the students. Among the utilities and services planned are heads, a projection booth, and heating and ventilating systems. In response to a question by CAPT MANEES, LTJG SIMONSON stated that the ventilating system is planned to be capable of expansion to an air-conditioning system if funds are ever available.

CAPT MANEES observed that the building will be located across from the Public Works Department and the contractor's hut, in an area now occupied by two mockups.

COL FLOOM inquired as to the capacity of the bleachers. Mr. STEVENS said that the capacity at first will be about 400 students. Later on, when and if a balcony is installed, the seating capacity will be increased to about 450. The balcony is considered desirable for small groups, who could look down on the Board and have better visibility than from the lower bleachers.

CAPT WAGNER asked whether the working space of 70' x 100' would be adequate. Mr. STEVENS replied that it is as large as funds permit, and that it is considered the optimum area under the circumstances. CDR KIRK-PATRICK remarked that the operating area of a similar device at Quantico is only 70' x 50'. CAPT WAGNER said that there is no good basis for comparison between the two.

CAPT WAGNER pointed out that before the device is completed with all frills, perhaps a million dollars will have gone into it. He expressed some doubt as to the adequacy of the proposed working area, and questioned the wisdom of letting the scope of the entire enterprise be limited by the amount of money available for initial construction of the building -- some twenty percent of the total cost.

Mr. STEVENS remarked that the proposed working space was considered adequate.

CAPT MANEES explained that the sum of \$305,000 had originally been requested for construction of the building, but that only \$198,000 had been made available. For the smaller amount it will be possible to construct a building of the same size as originally envisaged, but less satisfactory in other respects. He expressed the opinion that any changes foreseen as desirable could be accomplished at a later date when more money may be available, without ripup or tearup. LTJG SIMONSON verified this statement.

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CAPT MAGNER hoped that this would work out, and that the cart would not be put before the horse.

Maj McHENRY posed the question of security measures for the Teacher.

Mr. STEVENS replied that the question had not been definite, but that security measures might be comparable to those protecting the Supporting Arms Evaluator. He expressed the opinion that the device would ultimately be classified RESTRICTED, although the lectures to be conducted in conjunction with it would probably be CONFIDENTIAL. The building would, of course, be securely locked, but aside from this only normal security measures should be sufficient.

CDR MORGAN inquired as to whether the building could be expanded, envisaging the possible need for a larger operating area.

CAPT MANHES said that the building would not be constructed with expansion in mind. He stated that for \$198,000 not all the conveniences desired could be obtained. For example, the tiered seating arrangement was to have been of concrete if the full amount of money had been granted, but is now to be constructed of wood. The heating unit will not be as desired, but space will be provided for its installation at some possible future time. The same applies to air conditioning. Construction of the building will allow for later installation of a balcony, without alteration. The lesser sum does not provide for a driveway, and heat and power facilities will extend only about five feet from the building; other funds must be found to hook them up. Electrical wiring will be complete under the \$198,000 figure, however. Except for the wooden tiers, the structure of the building will be more or less as desired, but the exterior appearance will leave something to the imagination. The building will be a permanent structure.

A discussion of the device itself followed, with emphasis on such features as can now be foreseen.

Mr. STEVENS distributed copies of preliminary specifications, and read the portions of them applicable to the Teacher's concept as it has heretofore been discussed. He suggested then that questions be put by those present.

In reply to a question, Mr. STEVENS stated that the 70' x 100' operating area is to be circled by a pipe rail and walk, so that ordinarily there will be no traffic across the Board. The area is considered adequate. The scale of area and objects to be shown may be varied.

COL FLOOM asked whether two miles is considered to be the beach head line, or whether this will be arbitrary in different operations. Mr. STEVENS replied that it would be arbitrary. COL FLOOM expressed the opinion that the beach head line ought to be a point reached by the troops.

CDR KIRKPATRICK pointed out that the terrain model will be constructed to allow the terrain to be moved on the Board. The Trainer will cover one phase of an amphibious operation at a time, and the stage can be reset when the troops are ashore. The position of terrain and waterline can be varied.

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CAPT MANEES said that comments on this point are welcome, since the purpose of this conference is to "firm up" the plans for the Teacher. He requested COL FLOOM to look into this problem, and to consult with Mr. STEVENS and the others responsible for designing the device, so that the maneuvering area will be as adequate as possible.

Mr. STEVENS said that the terrain will come in sections six feet square, which can be added or taken away to give the effect desired. It will not be a permanent installation, so far as terrain is concerned. The terrain can be stored and brought out as necessary.

CDR GUNN inquired whether there is to be separation of Battalion Landing Teams. Mr. STEVENS replied that there would be room for separation, depending upon the scale used.

CDR INGLING asked what will be the length in yards of the actual landing beach. Mr. STEVENS advised him that the scale is not set. There are no limitations, except the physical limitation of 70 feet. CDR INGLING inquired as to the physical size of the ship models in variations from a ten thousand yard beach to a twenty thousand yard beach, for instance; would the ships themselves be changed? Mr. STEVENS pointed out that there must be a certain amount of give and take with regard to scale models; certain limitations are inherent. Models cannot be made too small, for reasons of visibility and identification. There will have to be a sliding scale; ship models will be larger for larger-scale operations, but not proportionately so. The exact scale between battleships and LCRs could never be kept, of course. He promised that no model will overlap in size any larger-type vessels.

CAPT MANEES inquired whether the models would be moved in automatically, on conveyors. Mr. STEVENS said that no particular method of conveying has yet been decided. The space in which they can move is fixed by mechanics, rather than the freer field of movements that could be attained by use of electronics.

CDR INGLING asked whether it would be possible to send in four RLTs on a twenty thousand-foot beach line with 5,000 feet between the landing beaches. Mr. STEVENS stated that the boat lanes can be placed in any position relative to one another, and relative to the beach.

CDR INGLING inquired as to whether the boat lanes will be bent or straight. Mr. STEVENS replied that design studies would show what is feasible in this connection. CDR INGLING recommended that they be bent rather than straight. He pointed out that if the device is to cover all situations, provision should be made for operations where lanes might have to go around shoals, obstructions, etc.; can this be done? CDR KIRPATRICK said that Mr. BIRKEL has thought of a method of allowing some movement, though probably not ninety degrees.

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CAPT WAGNER asked whether provision had been made to switch to alternate plans, if this should seem desirable in problems for which the device will be used. CAPT MANNEES pointed out that somewhere along the line there must be a compromise between what is desirable and what can be had.

CAPT WAGNER asked how long it would take to change the terrain, to which Mr. STEVENS replied that this could be accomplished in a matter of two or three hours. CAPT WAGNER explained that he meant changing from a cold start, to completely new terrain. Mr. STEVENS said that a new type of terrain could be obtained in about two weeks. CAPT MANNEES expressed the opinion that this would hardly be worthwhile except in special cases, such as fleet exercises. CAPT WAGNER pointed out that an amphibious invasion might at some time be planned on this device, necessitating procurement of terrain suitable to the specific operation.

CDR INGLING inquired as to whether anything can be built into the device to take account of varying conditions of tides, etc. Mr. STEVENS said this point had never arisen. CAPT MANNEES expressed the view that it would not be possible to go into such detail.

MAJ McHENRY inquired whether it would be feasible to have a machine to produce rubber models of terrain. CDR KIRKPATRICK replied that it would not; quite aside from the problem of finding somewhere to put the machine, the Special Devices Center is capable of producing terrain in two weeks, which would be fast enough.

Mr. STEVENS read from the preliminary specifications the Operational Requirements of the Evaluator, and the brief details of Assembly Circles, Debarcation Phase Requirements, etc. He pointed out that he is not going into too much detail here, but would like those concerned to give detailed advice on the subjects covered. CAPT MANNEES said that the civilian designers are to be in Little Creek through Friday, 10 August, but would like comments as soon as possible so that discussions on doubtful points may be held before that date. Suggestions should be written up in rough and sent to the Commanding Officer, Naval Amphibious Training Unit, for transmission to the representatives of the Special Devices Center and the Austin Company, who will contact the originators for future discussions as required.

MAJ McHENRY asked whether financial limitations rule out contemplation of electronic control of waves. Mr. STEVENS said that initially this would be the case, but that funds will in all probability continue to be available for improvements.

MAJ McHENRY expressed the opinion that the assault waves would take care of themselves; the big problem would be a question of timing, and of judging time in the unloading phase. He expressed doubt as to whether much of value could be accomplished along these lines with a track setup. CDR KIRKPATRICK said that he should have emphasized in the beginning that

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the complete operation will have to be broken up into phases, as in a play with several acts and scenes. The phases themselves may have to be broken down.

MAJ McHENRY inquired as to whether it is planned to have an entire wave on one section, or whether there will be individual control. Mr. STEVENS stated that there would be individual control. CAPT MANEES pointed out that there would be speed controls for the various types of landing boats.

Mr. STEVENS said that the Amphibious Assault Teacher and Evaluator is planned as an overall device, which will include a number of lesser devices to amplify individual demonstrations. All phases cannot be shown simultaneously. CDR INGLING asked precisely what could be shown at the same time. Mr. STEVENS replied that Gunfire Support can be portrayed, to a limited extent, but that the Gunfire Support has its Supporting Arms Evaluator and the Air Support School its Air Support Display Board for purposes of detailed instruction. The overall picture is portrayed here. There will be some planes in the air.

CDR INGLING asked whether provision is to be made for helicopters. Mr. STEVENS replied that helicopter observation was provided for, but that the problem of transport by helicopter has not been studied. The effect of this innovation upon the task of the device should be explored and written up.

CDR GUNN inquired as to provisions for portraying submarine attack; he wondered whether it might be possible to allow for a relationship between ships and attacking submarines. Mr. STEVENS thought this would be possible but very expensive. CAPT MANEES said that there was no objection to introducing the idea, though whether it could be accomplished in view of present financial prospects was another story. The idea should, however, be in the record. CDR GUNN said he had in mind electronic control of ship and submarine somewhat along the lines of what exists on Submarine Attack Teachers at New London and Mare Island, with both ship and submarine moving at will. Mr. STEVENS suggested that this idea be written up and submitted.

CAPT MANEES pointed out that during the loading phase there are perhaps a hundred extra boats milling around; possibly something could be done along anti-submarine warfare lines during the movement to objective phase when there are not too many boats on the Board, though there would still be a hundred models present.

COL FLOOM brought up the question of using atomic "squibs" to fill in with during the defense against atomic weapons portrayal. Mr. STEVENS said that the question of "squibs" and small explosives is being considered. COL FLOOM asked whether it is planned to use "squibs" rather than puffs. Mr. STEVENS stated that it is planned to use both, the smoke puffs to indicate smaller explosions. CDR KIRKPATRICK observed that it is necessary to be careful with explosives on this costly device.

CDR INGLING inquired as to whether any provision has been considered to allow revision of operations upon damage assessment. Mr. STEVENS said that this question has not yet been considered, but thought it possible. CDR INGLING expressed the opinion that there should be visual methods of

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indicating damage in the various areas. In this case, if the device is so designed that it can be stopped at any point, a substitute or alternate plan is necessary, if one part of the device fails or all or any parts of the Board. Any problem that would come up in this type of consideration is merely routine, and leaves no scope for hasty decisions; this is undesirable from the operational standpoint.

CAPT MANEES expressed the opinion that this problem can be worked out satisfactorily without too much change in the device, but would hesitate to say definitely at this time. CDR KIRKPATRICK thought that this could be done, since there can be alternate control mechanisms; even as the device is now designed there is a possibility that it could be done. CDR INGLING said that it would be well to be able to stop part of the ship to Shore Movement, while allowing the rest of the movement to proceed, upon assumption of localized damage. CAPT MANEES said that there is room for four battalions; one or two beaches could be stopped while the movement on the others continues. CDR INGLING said that it would be desirable to take into account ship damage as well as boat damage. Mr. BIRKEL replied that he would like a diagram of what CDR INGLING has in mind, if this is possible. CDR INGLING expressed the belief that such diagrams are available within Amphibious Group TWO. Mr. BIRKEL stated that in all problems of surface movement, diagrams should be submitted in as much detail as possible. Then, in the design study, it can be determined how close the manufacturers can come to exactly what is desired.

"CDR INGLING remarked that in CONVEX I, the plans took into account various conditions and gave planned solutions, etc. By looking over these plans, the designers could pretty well get the idea. He emphasized the desirability of having a device flexible enough to provide for the use of alternate plans, in the interest of realism.

CAPT MANEES pointed out that the designers are not amphibious warfare experts (though they are rapidly becoming so). They are able to recognize the problems brought up, but should have more than suggestions; their need is for pretty exact information.

CDR GUNN, referring again to the possibility of managing the device electronically, inquired as to the feasibility of using a "bug". Mr. BIRKEL observed that in the interest of a realistic portrayal, this might not be desirable. In ASW training devices, where the periscope is lowered most of the time, the use of a bug with cable attached is practicable. Here, with less limited visibility, it would not be a good thing.

CAPT MANEES and Mr. STEVENS again urged that detailed suggestions be submitted while the civilian party is on the Base, but emphasized that this would not be the last chance to consult with them. They will return with a design study at a later date.

MAJ McHENRY mentioned that the Burroughs Company makes periodic inspections of equipment it has manufactured, to see what repairs are required, etc. He desired to know what provision for such inspections and upkeep is to be made with respect to the Assault Teacher and Evaluator. Mr. STEVENS

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stated that there would be a complement of Tradewomen to keep it running, as in the case of the Supporting Arms Evaluator. Funds for maintenance will also be provided.

CDR LINERMAN expressed the view that there are two distinct problems of presentation with respect to this device, one flexible and one rigid. The former has so far been the topic of discussion. Concerning the latter, he asked whether it would be possible to have vertical projection of the Ship to Shore Movement. Mr. STEVENS indicated on the floor plan that at one end of the building there is a platform thirty inches high, with chart boards and space for a screen. This apparatus will allow any type of presentation desired.

CAPT MAHES asked COL BARTON to be free with suggestions, stating that from the Army's point of view it might be desirable to have a somewhat different type of terrain from that suggested by the Troop Training Unit.

COL FLOOD stated that he had a revision to suggest for paragraph 3.1.2.9 of the preliminary specifications submitted by the Special Devices Center. The paragraph should read as follows:

"Size and Scale of Evaluator. -The Evaluator will measure about seventy feet (70') by one hundred feet (100')(scaled to present about two (2) miles of landing beach area with at least two (2) miles inland and at least ten (10) miles to seaward, varying the proportion of sea and land surfaces necessary in phases to portray a complete beach head seizure operation). These scales may, of necessity, vary with the type of terrain model used." This suggestion appeared to meet with general approval.

Mr. BIRKEL remarked that he would like advice on how deep the final terrain should be. CAPT MAHES said that in view of this device having been conceived for use by Troop Training Unit and possibly Army students, he would like the point of view of the Marine command on the subject. It would not be desirable to restrict depth any more than necessary.

CDR KIRKPATRICK said that the designers wish to know what kind of terrain to furnish when the device is installed. It can be replaced later on, if necessary. CAPT MAHES stated that he did not want the device restricted to island problems. There should be facilities for land mass problems also. Mr. BIRKEL said that it has been suggested that the same terrain be used to portray various land mass areas by the shifting around of the various sections. It could be shifted from island to mainland to peninsula, etc., and various types of islands could be used. CAPT MAHES observed that this would be about what is desired. It is not necessary for general training purposes to duplicate any particular land mass area.

CDR MORGAN inquired as to whether it is contemplated that maps will be provided. If maps are given to students, quite large quantities will be used up. Mr. STEVENS said that maps could be provided within reasonable limits,

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though probably not in sufficient quantity for 400 students at a clip. CDR MORGAN said that they would only need to be work charts covering the squares of the area.

CDR GUNN wondered what the contemplated limits of land mass are to be; might they include a whole continent? CAPT MANKEE said that the device is primarily for instruction in problems connected with landings on the beach. Some terrain is desired, but not enough to cover the entire Board. It is necessary to compromise somewhere. Mr. STEVENS said that the reason for providing the terrain in sections is to provide flexibility in the amount used. CAPT MANKEE observed that the device is designed to be helpful from both the troop and the naval angle.

CDR MORGAN suggested that it might be feasible to provide sufficient land area so that the device could be used for land problems. This would increase its usefulness at a relatively small cost. CAPT MANKEE replied that the Teacher is designed for the Ship to Shore Movement. Upon completion of the assault, the problem can be halted and more terrain put in.

COL FLOOM said that he supposed when the general unloading phase has been reached, there will be no transports at eighteen thousand feet; the seaward side will presumably be cut down as the operation progresses. It was agreed that this assumption is correct.

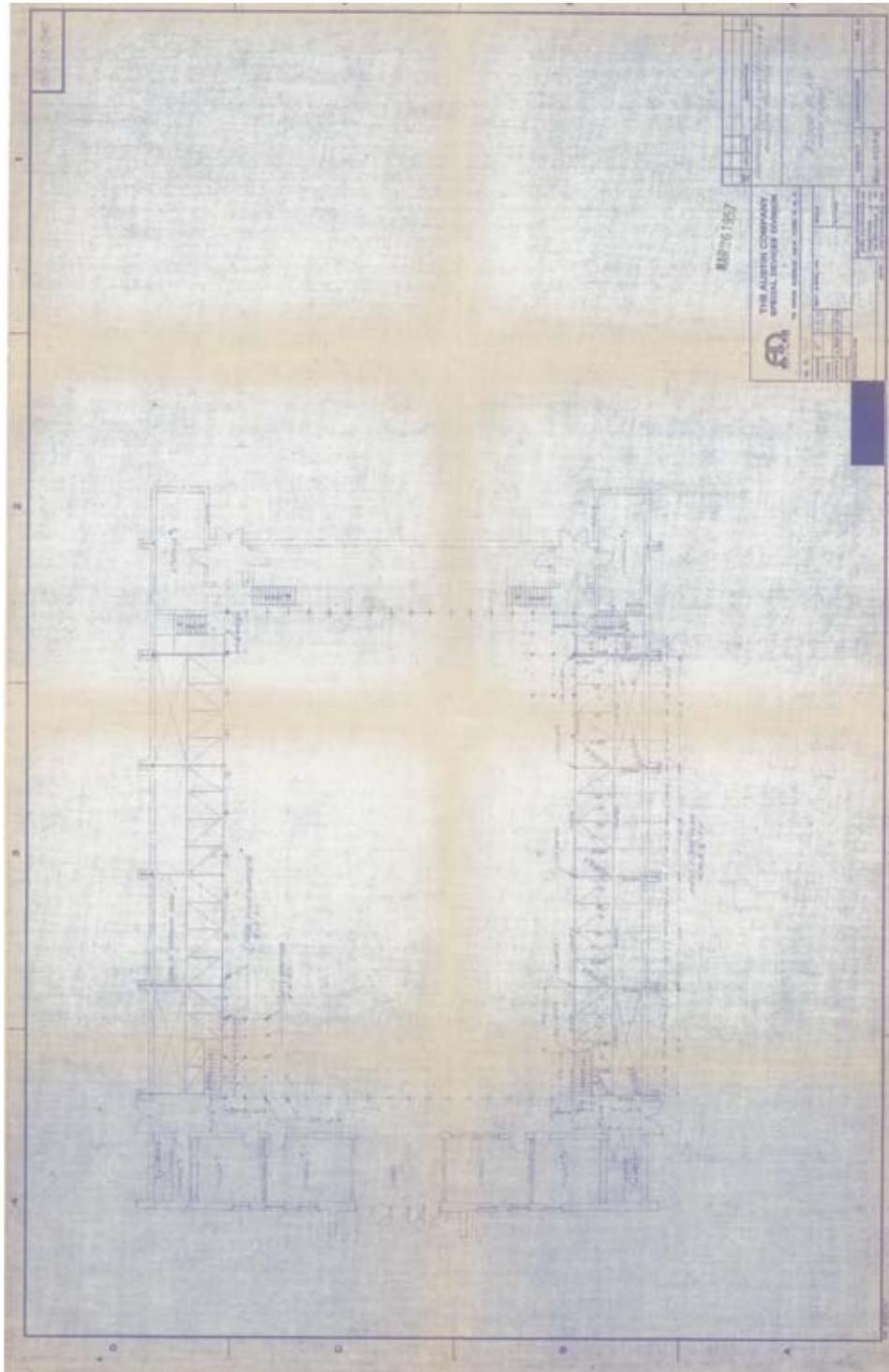
Mr. STEVENS pointed out that in connection with planning for additional terrain, the storage problem must be considered. There is no superfluity of storage space in the building itself. CAPT MANKEE suggested that a Quonset hut might be moved next to the Teacher building to provide additional storage space, as has been done with the Supporting Arms Evaluator.

CAPT MANKEE pointed out again that all the suggestions made at this conference have been general. They should be reinforced by specific and detailed recommendations at an early date.

The conference adjourned at 1125.

E. SAMPLE BLUEPRINTS USED TO CREATE X3D MODEL

1. Proposed Catwalk (The Austin Company, March 26, 1957)



2. Proposed Floor Plan (The Austin Company, October 1, 1956)

APPENDIX G. PROJECTOR COMPARISON

A. INTRODUCTION

This appendix contains a listing of all projectors considered for the cost analysis presented in Chapter VII of this work. The projector selected was the Epson Powerlite Pro GL5150NL. The price listed in this table is the manufacturer's suggested retail price (MSRP) during the summer of 2009. For the cost assessment, a price of \$2189 was found in the Michigan University Store at

<http://universitystores.msu.edu/html/whatsnew/epsonpricelist.asp>.

B. PROJECTOR COST COMPARISON TABLE

Projector	Lumens	Contrast Ratio	Throw Ratio Range (Std. Lens)	Cost
Epson Powerlite 8300NL	5200	1200:1	1.7 to 2.2	\$7999
Sanyo PLC-XP200L	7000	2200:1	1.7 to 2.0	\$7899
Panasonic PT-D5700U	6000	2000:1	72.6 Ft Throw Distance	\$6799
Sanyo PLC-XP100L	6500	2000:1	1.7 to 2.0	\$6595
Epson Powerlite Pro G5350NL	5000	1000:1	1.54 to 2.5	\$5099
NEC NP3150	5000	600:1	1.5 to 2.0	\$4637
Panasonic PT-D4000U	4000	1600:1	72.9 Ft Throw Distance	\$4399
NEC NP2150	4200	600:1	1.5 to 2.0	\$4174
Epson Powerlite Pro GL5150NL	4000	1000:1	1.54 to 2.5	\$4099
Sanyo PLC-XT25	4500	1000:1	1.6 to 2.1	\$3795
NEC NP1150	3700	600:1	1.5 to 2.0	\$3769
Epson Powerlite 6110i	3500	600:1	1.46 to 2.3	\$2899
Epson Powerlite 1825	3500	500:1	1.46 to 2.3	\$2299
NEC LT380	3000	600:1	1.5 to 1.8	\$2199
Panasonic PT-F200U	3500	400:1	29.8 Ft Throw Distance	\$2129

Sanyo PLC-XU105	4500	500:1	1.15 to 1.85	\$1995
NEC NP905	3000	500:1	1.5 to 1.8	\$1935
BenQ M771	3000	2000:1	13.3 Ft Throw Distance	\$1799
Sanyo PLC-XU88	3000	500:1	1.38 to 2.17	\$1795
NEC LT280	2500	600:1	1.5 to 1.8	\$1499
Epson Powerlite 1710C	2700	400:1	1.6 to 1.8	\$1449
Epson Powerlite 1705C	2200	400:1	1.6 to 1.8	\$1149
Epson Powerlite 1715C	2700	400:1	1.6 to 1.8	\$1099
Epson Powerlite 1700C	2200	400:1	1.6 to 1.8	\$999
Epson EX90 Multimedia	2600	400:1	1.6 to 1.8	\$899
Hitachi CP-X401	3000	400:1	1.5 to 1.8	\$866
NEC VT800	2700	500:1	1.5 to 1.8	\$849
Hitachi CP-X301	2600	500:1	1.5 to 1.7	\$760

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